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APPLICATION OF A DESIGN MORPHOLOGY TO THE MX/OCC DEFINITION OF A FAULT DETECTION AND DISPATCH SYSTEM

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September 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report includes the second year activities in which six criteria for Fault Detection performance were modelled and 180 candidate systems evaluated by a multiple criterion function based on 94 input variables. A Monte Carlo simulation of the maintenance activities of an MX Cluster was developed to aid in estimating input variables, and is included. The application of this design morphology appears to be effective on an unstructured problem and provides a useful vehicle for clearly defining the functions and tasks that meet the needs of FDD and hence, clarify the man-machine interactions.

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ABSTRACT

This research is part of a continuing effort to improve aerospace system design methods and to consider human resources and logistics properly during the design procedures. The approach used is a structured decision process which was successfully demonstrated in FY 78 on relatively simple mechanical equipment and has now been shown effective in a larger, less structured problem, the Fault Detection and Dispatch, (FDD), activities of the MX System. This report includes the second year activities in which six criteria for FDD performance were modelled and 180 candidate systems evaluated by a multiple criterion function based on 94 input variables. In support of this analysis a Monte Carlo simulation of the maintenance activities of an MX Cluster was developed to aid in estimating input variables, and is included in this study.

The application of this design morphology appears to be effective on an unstructured problem, including achievement of practical conclusions from the large scale optimization procedures. This design morphology provided a useful vehicle for clearly defining the functions and tasks that meet the needs of FDD and hence, clarify the man-machine interactions. Other advantages of this design morphology were observed and identified.

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Benjamin Ostrofsky
Principal Investigator

APPLICATION OF A DESIGN MORPHOLOGY TO THE MX/OCC DEFINITION OF A FAULT DETECTION AND DISPATCH SYSTEM

UNIVERSITY OF HOUSTON

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFHRL	Air Force Human Resources Laboratory
AFOSR	Air Force Office of Scientific Research
a_i	Relative weight of the $i^{\underline{th}}$ Criterion
AMF	Alert Maintenance Facility
AOCC	Alternate Operations Control Center
APR	Annual Percentage Rate
ATE	Automatic Test Equipment
AUS	Automatic Umbilical System
AVE	Airborne Vehicle Equipment
BMO	Ballistic Missile Office
C^3	Command, Control, and Communications
CAMMS	Computer-Aided Maintenance Management System
CMF	Cluster Maintenance Facility
COMSEC	Communications Security
CPC	Code Processing Center
CTOCU	Central Technical Order Control Unit
DAA	Designated Assembly Area
DASC	Designated Assembly Support Center
DB	Data Base
DL	Depot Level
E/E	Enter/Exit
FDD	Fault Detection and Dispatch
FY	Fiscal Year
HF	High Frequency
IL	Intermediate Level
IMU	Inertial Monitoring Unit
LCC	Launch Control Center
LED	Light Emitting Diode
LRU	Line Replaceable Unit
MCC	Maintenance Control Center
MF	Medium Frequency

MGCS	Missile Guidance and Control System
MNLE	Logistics Engineering Organization in BMO
MOSE	Mobile Operational Support Equipment
MSS	Mobile Surveillance Shield
MX	Missile X
N-L	No-Launch
OB	Operations Base
OCC	Operations Control Center
OL	Organizational Level
OSE	Operational Support Equipment
PI & A	Personnel Identification and Authentication
PLU	Preservation of Location Uncertainty
PS	Protective Structure
ROSE	Resident Operational Support Equipment
ROSEE	Resident Operational Support Equipment Enclosure
R/R	Remove and Replace
RS	Reentry System
SAC	Strategic Air Command
SALT	Strategic Arms Limitation Treaty
SAL VER	Salt Verification
SAMSO	Space and Missile Systems Organization (now BMO)
SIMMX	MX Maintenance Simulation
SMSB	Strategic Missile Support Base
STV	Special Transport Vehicle
TEL	Transporter Erectro Launcher
TO	Technical Order (Document)
USAF	United States Air Force
V & E	Vehicle and Equipment
VLF	Very Low Frequency
WCP	Wing Command Post
WSC	Wing Security Center
x_i	$i^{\underline{th}}$ Design and Development Criterion
y_k	$k^{\underline{th}}$ parameter
z_j	$j^{\underline{th}}$ submodel

1.0 INTRODUCTION

1.1 Statement of Objectives

This research has the following objectives:

1.1.1 Augment the current research into definition of human factors and metrics which influence the decision structure of design.

1.1.2 Extend the investigation of analytical methods for successfully integrating qualitative and quantitative information into a multivariate criterion function.

1.1.3 Define the tasks necessary for clarifying the decision structure and methodology for the design and implementation of a high technology, large scale system.

1.1.4 Demonstrate the applicability of the design morphology to the planning for a system design.

1.2 Background

This research is part of a continuing[1,2,3,] Air Force effort to improve the techniques used for designing aerospace hardware. Specifically, the difficulties of properly emphasizing human factors[4] in the development of Air Force Systems have often created both operational problems in the field and less than desired efficiency in training and maintenance expenditures. Hence, the need for the equipment designer to understand the impact of human factors implies a need to assure adequate recognition by all planning approval agencies of these factors in the design decision

structure.

A design morphology published earlier[5] provides a decision structure for the development of a technological system which appears to be highly effective when used to design USAF equipment. The relationship between the semantics of the design morphology and those of the USAF were clarified[2] and related to the existing literature in both the human factors and engineering design areas. This effort provided an excellent case study in interdisciplinary communications.

The major thrust of the FY 78 research was the *application* of the design decision structure to a current, relatively small design problem, the service stand for the Emergency Power Unit of the F-16 Aircraft[6]. The principal investigator took on the role of advisor to the design engineers at General Dynamics, Fort Worth plant and, by coordinating with these engineers in regular and frequent sessions proceeded to apply the morphology successfully. Acceptance of the human factors requirements was dramatically demonstrated by defining a multiple criterion function which included criteria that required human resource considerations in combination with hard, engineering data. The ease with which the designer reviews were satisfactorily accomplished helped to convince the General Dynamics management that this methodology was indeed effective when properly applied.

Specifically, accurate design requirements were defined quickly; a detailed record of design decisions were readily available and very clearly presented; knowledgeable trade-offs among the traditionally "hard"

criteria were made with "soft" criteria that related more directly to the human resource environment; a clear delineation was achieved of the "best" candidate system of those considered; and finally, an explicit level of "growth" for each parameter (input variable) was identified from a computer search of the design space. The latter provided management guidance on where to allocate resources for performance improvement.

In view of the successful application to a small, hardware system, the decision was made to apply the morphology to a larger, more sophisticated USAF system. After some review, the problem of processing maintenance status change through dispatch, completion of corrective action, and post dispatch debriefing for the MX Weapon System was approved by SAMSO (now BMO), AFHRL, and AFOSR[1].

The research reported in this report completed the scheduled activities for FY 80. The activity analyses (See Figure 1-1) provided major inputs to the development, and is under continuous review.

There were three parts to the activity analysis, the maintenance study for the MX System (which developed into SIMMX, see Appendix C), facility location impact or maintenance (which was completed[1] in FY 79) and the input-output study for this research problem. These analyses provided the ability to establish the basic approach toward task definition (establishment of the "concept"[5] and the alternatives toward accomplishment of the task definition (candidate systems). All three studies were coordinated to preclude redundant effort.

The MX System maintenance study is being developed as a computerized Monte Carlo simulation of the maintenance of an MX cluster of

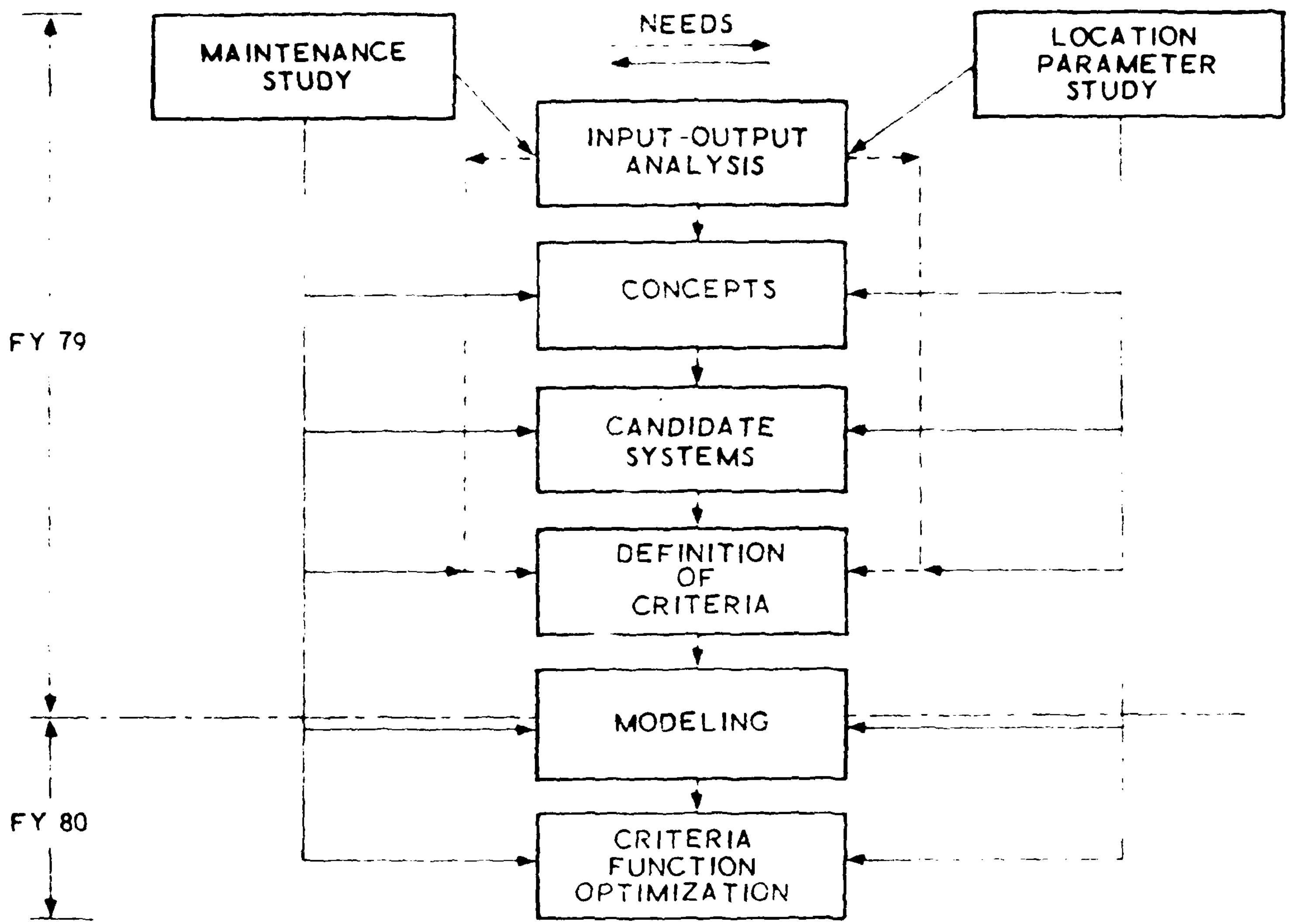

Figure 1-1: Study Information Flow

Protective Structures (PS) (See Appendix C). This model provides the capability to test and to evaluate variations of maintenance strategies for the MX cluster.

A parallel, but separate study was accomplished and coordinated with the MX maintenance study. This examined the MX System field geometry of 4000 sites of which approximately 200 may contain launchers. The purpose of this study was to accomplish an examination of MX System Activities that supplement the maintenance tasks, but yield equally important effects on MX System availability and on preservation of location uncertainty (PLU). This study related the site spacing to the effects on maintenance task times including transport to/from the DAA or the CMF, and was concluded in FY 79.

2.0 SUPPORTING RESEARCH AND DEVELOPMENT

2.1 Requirements

The basic requirements for this research are essentially the same as those described in FY 79[1]. However, the deployment and operations concept of the MX have changed several times during the past two years. Hence this activity has adapted to the configuration at the time of work accomplishment and may require additional review prior to final MX deployment.

Current planning by Strategic Air Command (SAC) for the MX/OCC includes the following:

1. Monitor force status
2. Communicate force status to higher authority

3. Dispatch and coordinate maintenance activities
4. Receive emergency action messages from higher authority and initiate launch actions as directed
5. Reprogram or retarget missiles
6. Control movement of missile/decays
7. Monitor physical security status and control security forces
8. Control access to designated areas

The following formal organizations are incorporated into the MX/OCC:

1. Wing Command Post
2. Launch Control Center
3. Maintenance Control
4. Wing Security Control

Development of the FDD will include the activities of Maintenance Control only, as well as those activities of the remaining controls that are necessary to the efficient accomplishment of Maintenance Control responsibilities.

Maintenance Control includes the following:

1. Job scheduling, and material control for missile maintenance, communication, Civil Engineering, and transportation.
2. Direct line communications capability from each composite area to all interfacing agencies
3. Monitor Force Status, dispatch and coordinate

maintenance activities and missile/decoy movement.

While the primary objective of FDD is to respond to item #3, it is recognized that the interaction of 1 and 2 have such a direct effect on any FDD system that a detail awareness of the accomplishment of these activities must be considered in its development.

Initial consideration for FDD was identified by Boeing[8] and for the most part still pertains:

1. In series site coverage
2. Individual trips to PS in sequence
3. Incorporation of PLU tactics
4. Computer directed Randomized Dispatch Schemes

Major FDD system outputs for MX Maintenance Control have been defined as follows:

1. Each PS monitored at least once every 60 seconds
2. 95% of potential faults are to be isolated to one LRU; the remaining 5% of potential faults are to be isolated to 4 LRU
3. There is to be a high level of automation to ease fault definition
4. Complete TO to be readily available (and highly automated)
5. TO Data easy to use
6. Efficient notification and dispatch
7. Maximum utilization of maintenance teams and equipment
8. Effective skill level mix for team composition
9. Minimum spares for planned system availability

Broad conditions prevailing as "inputs" for FDD are as follows:

1. Automated Monitoring Equipment
2. Software and Procedures for FDD
3. C^3
4. Flexible Dispatch Rules
5. The Maintenance Concept
6. Monitoring Equipment to be easy to operate and to maintain
7. Efficient Personnel Training Program
8. Effective Pipeline for personnel and spares

2.2 Operational Scenarios

Figure 2-1 identifies the basic FDD activity sequence from which assumptions can be made on the nature and location of these activities. Basically, the detect function is the recognition of a fault or discrepancy in the missile force (including OSE). The preciseness of location (PS, LRU, etc.) is left to the subsequent development of candidate systems. Once a fault is detected, the analysis function consists of the process of defining the nature of the fault, its location to the desired level of equipment, the requirements for resolving the fault and the appropriate scheduling of personnel. Dispatch includes the coordination of schedule implementation for command post, job control, transportation, and security. When the maintenance personnel arrive at the PS they clear security requirements ("Interrogate Security") for access to the missile or the associated equipment which may contain the fault. The maintenance tasks are accomplished and verification obtained by clearing

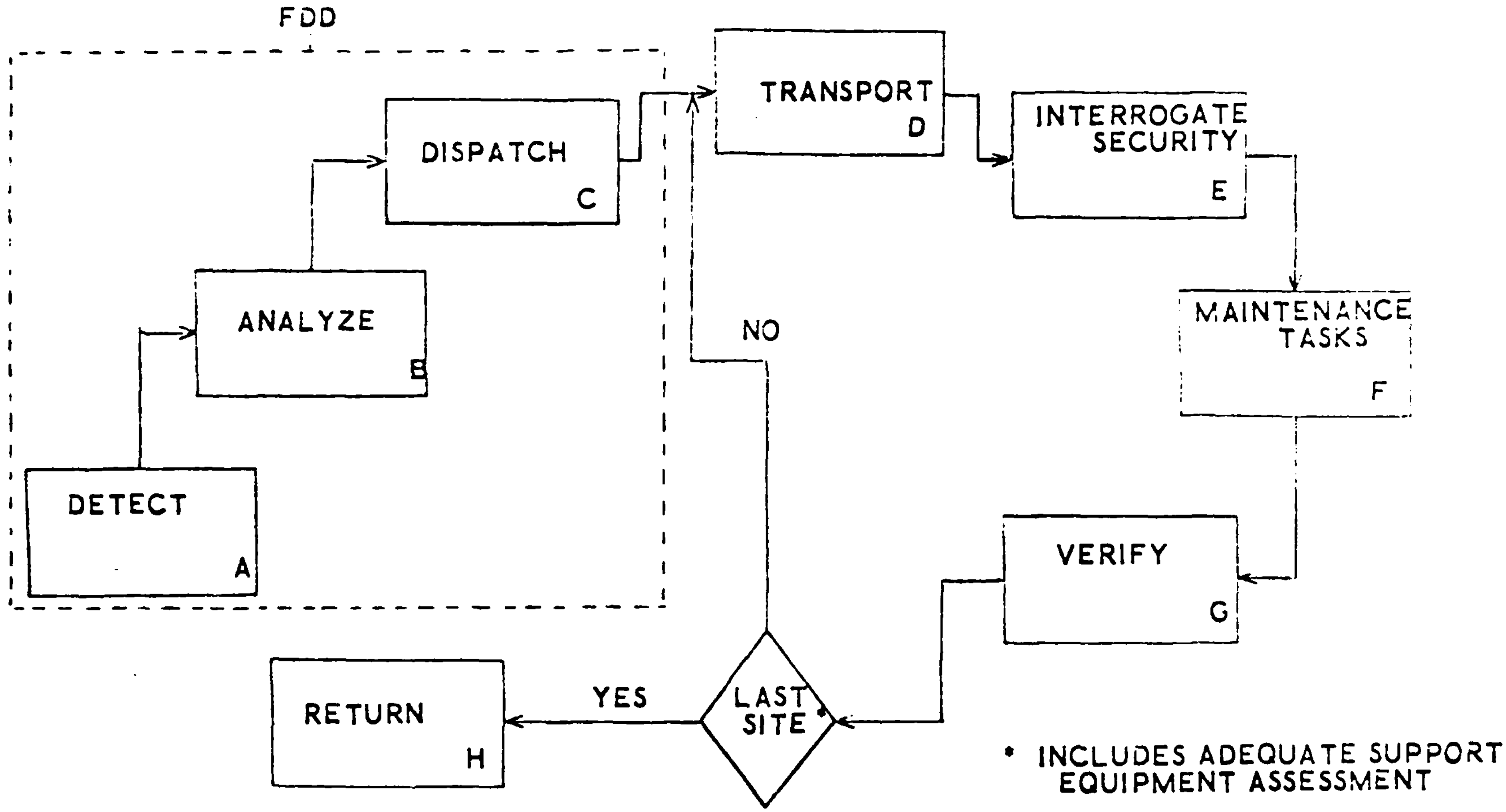

Figure 2-1: FDD Operations Flow

with Maintenance Control. The maintenance crew then proceeds to the next PS or returns to their point of dispatch as a function of the prevailing conditions.

In order to consider adequately all possibilities associated with Maintenance Control development, consideration was given to providing the task accomplishment (along with proper OCC coordination) to three levels of Maintenance Activities. These are listed:

I Fault Detection and Analysis in the OB

II Fault Detection and Analysis in the DAA

III Fault Detection and Analysis in the CMF

Each scenario is envisioned to accomplish fault detection and analysis for the missile force with simultaneous information display at the OCC for scenarios II and III. However, it is recognized that the CMF, DAA, and OB will require appropriate readout for any scenario that is developed. Further, the scenarios represent conceptual approaches recognizing that actual development may necessitate modifications to the scenario for operational expediency.

These scenarios have been described in the previous study[3] and their advantages and disadvantages presented. They are summarized below*:

2.2.1 Advantages of Scenario I (FDD at OCC)

1. Centralized Control
2. Standardized procedures more readily obtained
3. Constant and accurate knowledge of PLU

---

* Note that OB is analgous to SMSB, DAA/CMF to AMF.

4. Simpler distribution system for LRU
5. Reduced number of pieces of test equipment

2.2.2 Disadvantages of Scenario I (FDD at OCC)

1. High automation levels at OCC (Increased complexity at OCC)
2. High levels of redundancy required for automated scheduling
3. Effective Span of Control over dispatch teams will be difficult
4. Large number of Teams controlled from OCC

2.2.3 Advantages of Scenario II (FDD at DAA/CMF)

1. Reduced Span of Control over all maintenance activities
2. Easier transition from Minuteman organizational structure
3. Reduces OCC Staff Requirement
4. Simpler Personnel Scheduling Problem

2.2.4 Disadvantages of Scenario II (FDD at DAA/CMF)

1. Coordination of Wing Requirements is difficult
2. Increased test equipment costs
3. Variable Supply Costs
4. Increased manning for maintenance control
5. Decreased control over maintenance by maintenance commander
6. Reduced economy of Scale in LRU repair
7. Increased pipeline complexity

8. More command positions

9. Increased C^3 complexity

2.2.5 Scenario III Advantages (FDD at OB)

1. All maintenance management at one location
2. Economies of expertise and skill levels
3. Centralized Scheduling and Control
4. Centralized Maintenance Decision Making
5. Reduced Test Equipment and Inventory Requirements
6. Limited location knowledge
7. Reduced span of control

2.2.6 Scenario III Disadvantages (FDD at OB)

1. Parallel detection capability requirement at the OB and OCC
2. Increased management problems
3. PLU compliance problem in limiting location knowledge

The FY 79 Study[3] identified a subjective appraisal of each scenario for the respective areas of integrated logistics support where 1 represents the most desirable and 3 the least desirable (See Figure 2-2). This indicates the desirability sequence of the scenarios to be III, I, II, with Scenario III clearly more effective than Scenario II, the closest runner-up.

2.3 Candidate Systems

A candidate system by definition[5] includes each of the activities described in Figure 2-1. Hence, by identifying alternative methods for

accomplishing each activity, any combination of one method from each respective activity would constitute a candidate system.

		Scenarios		
		I (OCC)	II (DAA/CMF)	III (OB)
1.	Maintenance Planning	2	3	1
2.	Support and Test Equipment	3	2	1
3.	Supply Support	1	3	2
4.	Transportation and Handling	3	2	1
5.	Technical Data	3	2	1
6.	Facilities (OCC, OB, DAA, CMF)	1	3	2
7.	Personnel and Training	2	3	1
8.	Relative Costs	1	3	2
9.	Management Data	2	3	1

(1 is most desirable)

Figure 2-2: Relative Effectiveness of Each Scenario for Each Integrated Logistics Support Area

The alternatives for each activity were presented earlier[1] and are reviewed here for convenience.

2.3.1 Detect Function: This is the activity in the OCC, DAA, CMF, OB, or other organizations requiring notification (or readout of the occurance of a fault in the missile force. This function will probably be an automatic indication of some sort and be simultaneously readout with the responsible DAA/CMF for Scenario II or the OB for Scenario III (or possibly all three depending on the chosen candidate system).

Alternatives for the Detect function are:

1. Go-no-go Light Display
2. L.E.D. display
3. Audio alarm
4. Flashing status display
5. Simultaneous display with some combination of all 4 alternatives

2.3.2 Analyze Function

Given that a fault has been detected to the LRU level, the Analyze Function includes the determination of:

1. Location of the fault to the lowest equipment level required for the particular maintenance concept
2. Location of the Protective Structure
3. Fault criticality (i. e. safety or PLU criticality determination of missile launchability, etc.)
4. Preventive/corrective replacement equipment
5. Required team specialities for maintenance action
6. Estimated maintenance time at the PS
7. Alerting Transportation: Control, security control and other dispatch function organizations.

Alternatives for analyzing the fault will be largely determined by the particular concept and candidate system that is implemented. However, the Analyze Function can be:

1. Localized to the Subsystem Level

2. Localized to the LRU level

3. *Some combination of 1 & 2*

4. Related to Performance Threshold level

The latter implies the arbitrary determination of acceptable readouts from a given LRU (for example IMU precession rates). Changing the threshold level will affect the rate at which faults are identified.

2.3.3 Dispatch Function

This function accomplishes:

1. scheduling of proper team personnel
2. scheduling of vehicles and equipment
3. maintenance of the team status in correcting the fault
4. coordination with the detect and analysis functions
5. communication with dispatched teams.

Alternatives for this function are:

1. Organizing for specialized skills in each team to respond to a given fault
2. Organizing for a standard skill mix for each team with specialists
3. Organizing for a standard skill mix with technicians who are each multi-skilled

2.3.4 Transport Function

This function accomplished the actual transport of the maintenance team the required equipment for correcting the analyzed fault. Since

available vehicles will be used for this function, including backup from OB and other CMF and airborne vehicles if required, this function will have essentially the same alternatives for all candidate systems.

2.3.5 Interrogate Security

This activity is the means by which the maintenance crew achieves its security checks prior to accessing the PS and its support equipment.

2.3.6 Maintenance Tasks

These include all corrective tasks required to remove the fault that has been identified at OCC plus any preventive tasks that may be identified by the Analysis Function and/or the Maintenance Team at the PS.

2.3.7 Verification Function

These activities include:

1. Verification of complete corrective action for fault removed both at OCC and the Dispatch function organization
2. Verification of security requirements upon egress from PS
3. Determination of whether to return to base or to proceed to another PS for removal of another fault

2.3.8 Return Function

The maintenance team proceeds to another PS for correction of another fault or returns to base.

2.3.9 The Candidate System Set

The functions of Transport, Interrogate Security, Maintenance Tasks, Verification and Return (Sections 2.3.4 to 2.3.8) are all considered to be constant for all scenarios and their respect candidate systems. Hence, the candidate systems synthesized include the Detect, Analyze, and Dispatch Functions only, since the others, with the exception of Maintenance Tasks will remain relatively constant -- and, hence, will not influence the choice of the optimal candidate system significantly.

Figure 2-3 illustrates a typical alternative combination of functions or "candidate system". Since there are 5 alternative for Fault Detection, 4 for Analyze, and 3 for Dispatch, there are 60 Candidates that will require evaluation for each of 3 scenarios, or 180 candidate systems in the set (see Figure 2-4).

A DETECT FUNCTION	B ANALYZE FUNCTION	C DISPATCH FUNCTION
4. Flashing status Display	2. Localize to LRU	3. Make-up Specialized Team After Fault Analysis

Figure 2-3: Typical Candidate System

2.4 Criteria

In order to evaluate the potential performance of the candidate systems criteria must be explicitly identified[5]. Since the FDD is only one

	A	B	C
SCENARIOS	DETECTION	ANALYZE	DISPATCH
I	1	1	1
II	2	2	2
III	3	3	3
	4	4	
	5		

180 Total Candidate Systems To Be Analyzed

Figure 2-4: The Set of Candidate Systems

of many "sub-systems" in the MX program, within this constraint more explicit measures must be identified. Hence a questionnaire was developed[1] and opportunity was provided for the respondants to add, delete, or change criteria. Ten key individuals identifed by BMO/MNLE were given the questionnaire, and the following criteria resulted:

1. Availability - the MX force operational availability
2. Comparative Costs: - the cost of a given candidate system relative to a standard cost
3. Team Utilization: - the level of activity of the maintenance teams measured as a fraction of their available time or other suitable metric.
4. Vehicle and Equipment (V & E) Utilization: the level of activity of all vehicles and equipment necessary for MX force readiness measured as a fraction of their available time or other suitable metric.
5. Preservation of Location Uncertainty: the ability of the candidate system to preserve location uncertainty.
6. Strategic Arms Limitation Verification (SAL VER) The ability of a candidate system to support SAL VER as identified by an acceptable metric.

These criteria will be used to explicitly evaluate the performance of the 180 candidate systems.

2.4.1 Definition of Relative Importance

The questionnaire[1] provided the opportunity for respondants to identify their opinion regarding the relative important of each criterion.

Figure 2-5 shows the response to this questionnaire. SAL VER presented the only bimodal response, that is, the ratings were all at 7 or above or they were at 1 or below. After consultation, the high values were eliminated since SAL VER was considered by BMO to be a total MX criterion, and that conditions imposed by SAL VER would provide higher constraints upon candidate system performances than it would as a direct criterion on FDD performance evaluation.

Figure 2-6 then represents the criteria and their respective relative importance. Each criterion will be modeled in terms of measurable (or estimable) variables of the candidate systems, all to be described below.

		Respondants to Questionnaire									
i	Criterion, x_i	1	2	3	4	5	6	7	8	9	10
1.	PLU	10	10	10	10	8	10	10	9.5	10	9
2.	Availability	9	6	10	10	8	9	9.5	10	10	10
3.	Comparative Costs	6	9	6	4	1	8	5.5	9	6	5
4.	Team Utilization	7	8	10	5	6	0	6.5	5	7	7
5.	V & E Utilization	7	8	10	4	6	0	6.5	0	6	8
6.	SAL VER	2	10	0	8	7	7	0	0	1	10

Figure 2-5: Raw Data Responses to Questionnaire

i	x_i	Mean Ranking	a_i
1.	PLU	9.650	0.231
2.	Availability	9.150	0.219
3.	Comparative Costs	7.895	0.189
4.	Team Utilization	7.554	0.181
5.	V. & E. Utilization	6.938	0.166
6.	SAL VER	0.600	0.014
		41.787	1.000

Figure 2-6: Table 1 - Design Criteria, $\{x_i\}$ and Their Respective Relative Weights, $\{a_i\}$

2.5 Parameters and Submodels

In order to approach the quantitative estimates of the criteria a set of "elements" is synthesized for each. The original attempt[1] has been significantly up-dated as the modelling effort matured during this fiscal year*. Both the parameter set and the submodel set have been adjusted to reflect the current modelling results and Figures 2-7 to 2-12 show the respective constituent submodels (z_j) and parameters (y_k) for the given criterion (x_i). The computerized version is shown in the program printout of Appendix B .

*"parameter" is defined to be a directly measurable or estimable characteristic of the candidate system[5].

"submodel" is defined to be a characteristic requiring synthesis of one or more parameters to estimate the value of that characteristic[5].

x_1, PRESERVATION OF LOCATION UNCERTAINTY, (PLU)

Submodel z_1 - Number of personnel for FDD
z_8 - Number of actions per month

Element of y_k:

k		Description	k		Description
1	-	Number of CMF	30	-	Number of RS no launch failures/mon. per missile
2	-	Number of OB	31	-	Number of MOSE/MGCS no launch failures/mon. per missile
3	-	Number of multiple skill teams	35	-	Speed of helicopter
4	-	Number of inspection teams	36	-	Speed of MSS
5	-	Number of AVE moving teams	37	-	Speed of van
6	-	Number of OSE R/R teams	39	-	Number in AVE R/R team
7	-	Number of C^3/security repair teams	50	-	AVE removal time
8	-	Number in multiple skill team	51	-	OSE removal time
9	-	Number in inspection team	55	-	Number of DAA's
10	-	Number in AVE moving team	59	-	Number in helicopter teams
11	-	Number in OSE R/R team	60	-	Number of personnel per MSS
12	-	Number in C^3/security repair team	61	-	Number in van team
13	-	Number of AVE R/R teams	62	-	Number of FDD personnel per CMF
14	-	Number of helicopters assigned to FDD	63	-	Number of FDD personnel per OB
15	-	Number of vans assigned to FDD	64	-	Number of FDD personnel per DAA
16	-	Number of MSS	65	-	Fraction of no-launch failures req. helicopter
18	-	Distance between PS	66	-	Number of persons at CAMMS need to know missile loc.
19	-	AVE emplacement time	67	-	Shell-game cycle time
20	-	OSE emplacement time	88	-	Number of security teams for FDD
21	-	AVE inspection time	89	-	Number in FDD security team
22	-	OSE inspection time	92	-	SAL verifications
23	-	AVE repair time	93	-	Time spent at each PS for PLU
24	-	OSE repair time	94	-	Time to enter/exit site
25	-	Number of maintenance personnel knowing any missile loc.			
29	-	Number of booster no launch failures/mon. per missile			

Figure 2-7: Criterion x_1 , Preservation of Location Uncertainty (PLU) (Table II)

x_2, AVAILABILITY

Submodel	z_3	-	Task time (minutes)
	z_4	-	Dispatch time (minutes)
	z_8	-	Number of actions per month

Element of y_k:

k		Description
18	-	Distance between PS (feet)
19	-	AVE emplacement time (minute)
20	-	OSE emplacement time (minute)
21	-	AVE inspection time (minute)
22	-	OSE inspection time (minute)
23	-	AVE repair time (minute)
24	-	OSE repair time (minute)
29	-	Number of booster no launch failures/mon. per missile
30	-	Number of RS no launch failures/mon. per missile
31	-	Number of MOSE/MGCS no launch failures/mon. per missile
35	-	Speed of helicopter (feet/minute)
36	-	Speed of MSS (feet/minute)
37	-	Speed of van (feet/minute)
50	-	AVE removal time (minute)
51	-	OSE removal time (minute)
52	-	Delay (minutes)
54	-	Speed of STV
56	-	Distance between DAA and CMF
58	-	Distance between CMF and PS
65	-	Fraction of no launch failures req. helicopter
92	-	SAL verifications (at least once per year)
93	-	Time spent at each PS for PLU (minute)
94	-	Time to enter/exit site (minute)

Figure 2-8: Criterion x_2, Availability (Table II, Cont.)

x_3, COMPARATIVE COST

Submodel	z_2	-	FDD equipment and facilities cost ($)
	z_5	-	FDD personnel cost ($)
	z_6	-	FDD vehicle cost ($)
	z_7	-	FDD operating and spare cost ($)

Element of y_k:

k		Description
1	-	Number of CMF
2	-	Number of OB
3	-	Number of multiple skill teams
4	-	Number of inspection teams
6	-	Number of C^3 security repair teams
13	-	Number of AVE R/R teams
14	-	Number of helicopters assigned to FDD
15	-	Number of vans assigned to FDD
16	-	Number of MSS's
17	-	Number of clusters
26	-	Base operating support cost ($)
27	-	Helicopter team personnel cost ($)
28	-	Van team personnel cost ($)
40	-	Cost/van ($)
41	-	Cost/MSS ($)
42	-	Cost/helicopter ($)
43	-	Personnel cost/OSE R/R team
44	-	Personnel cost/AVE R/R team
45	-	Personnel cost/multiple skill team
46	-	Personnel cost per AVE/OSE moving team
47	-	Personnel cost/inspection team
48	-	Personnel cost/C^3 - security repair team
49	-	Personnel cost/ROSE repair team
53	-	Number of STV
55	-	Number of DAA
57	-	Number of OSE moving teams
62	-	Number of FDD personnel per CMF
63	-	Number of FDD personnel per OB
64	-	Number of FDD personnel per DAA
68	-	Average pay for CMF personnel ($)
69	-	Average pay for OB personnel ($)
70	-	Average pay for DAA personnel ($)
71	-	*Cost per STV ($)*
72	-	Cost per CMF ($)
73	-	Cost per OB ($)
74	-	Cost per DAA ($)
75	-	Equipment cost per CMF ($)
76	-	Equipment cost per OB ($)
77	-	Equipment cost per DAA ($)
78	-	Inventory cost per CMF ($)
79	-	Inventory cost per OB ($)
80	-	Inventory cost per DAA ($)
81	-	Number of cranes/cluster
82	-	Number of cranes teams
85	-	Cost per crane ($)
86	-	Number of helicopter teams
87	-	Number of van teams
88	-	Number of security teams for FDD
90	-	Personnel cost/FDD security team
91	-	Personnel cost/crane team

Figure 2-9: x_3 - Comparative Cost
(Table II, Cont.)

Submodel z_3 - Task time (minutes)
z_4 - Dispatch time (minutes)
z_8 - Number of actions per month

Element of y_k:

k		Description
18	-	Distance between PS (feet)
19	-	AVE emplacement time (minute)
20	-	OSE emplacement time (minute)
21	-	AVE inspection time (minute)
22	-	OSE inspection time (minute)
23	-	AVE repair time (minute)
24	-	OSE repair time (minute)
29	-	Number of booster no launch failures/mon. per missile
30	-	Number of RS no launch failures/mon. per missile
31	-	Number of MOSE/MGCS no launch failures/mon. per missile
35	-	Speed of helicopter (feet/minute)
36	-	Speed of MSS (feet/minute)
37	-	Speed of van (feet/minute)
50	-	AVE removal time (minute)
51	-	OSE removal time (minute)
52	-	Delay (minute)
54	-	Speed of STV
56	-	Distance between DAA and CMF
58	-	Distance between CMF and PS
65	-	Fraction of no launch failures req. helicopter
92	-	Number of SAL verifications
93	-	Time spent at each PS for PLU (minute)
94	-	Time to enter/exit site (minute)

Figure 2-10: Criterion x_4 , Team Utilization
(Table II, Cont.)

Submodel	z_3 -	Task time (minutes)
	z_8 -	Number of actions per month

x_4, Team Utilization

Element of y_k:

k		Description
14	-	Number of helicopters assigned to FDD
15	-	Number of vans assigned to FDD
16	-	Number of MSS
17	-	Number of clusters
18	-	Distance between PS (feet)
19	-	AVE emplacement time (minute)
20	-	OSE emplacement time (minute)
21	-	AVE inspection time (minute)
22	-	OSE inspection time (minute)
23	-	AVE repair time (minute)
24	-	OSE repair time (minute)
29	-	Number of booster no launch failures/mon. per missile
30	-	Number of RS no launch failures/mon. per missile
31	-	Number of MOSE/MGCS no launch failures/mon. per missile
35	-	Speed of helicopter (feet/minute)
36	-	Speed of MSS (feet/minute)
37	-	Speed of van (feet/minute)
50	-	AVE removal time (minute)
51	-	OSE removal time (minute)
52	-	Delay (minutes)
53	-	Number of STV
54	-	Speed of STV
56	-	Distance between DAA and CMF
58	-	Distance between CMF and PS
65	-	Fraction of no launch failures req. helicopter
92	-	Number of SAL verifications/year
93	-	Time spent at each PS for PLU (minutes)
94	-	Time to enter/exit site (minutes)

Figure 2-11: Criterion x_5 , Vehicle and Equipment Utilization (Table II, Cont.)

Element of y_k :

$\underline{k}$		Description
81	-	Number of cranes/cluster
83	-	Seven days crane reliability
84	-	Minimum number of cranes needed per cluster

Figure 2-12: Criterion x_6 , SALT Verification (Table II, Cont.)

3.0 SUBMODEL DEVELOPMENT

These submodels are developed using the parameters defined and identified in Section 2.5, Figures 2-7 through 2-12. The submodels developed for the set of criteria are:

<u>Section</u>

3.1	z_1	Number of personnel for FDD
3.2	z_2	FDD equipment and facility cost ($)
3.3	z_3	Task time, (minutes)
3.4	z_4	Dispatch time (minutes)
3.5	z_5	FDD personnel cost ($)
3.6	z_6	FDD vehicle cost ($)
3.7	z_7	FDD operating and spares cost ($)
3.8	z_8	Number of actions per month

3.1 Number of Personnel for FDD, z_1

This submodel is a compilation of the total number of personnel required for FDD, and was synthesized by summing the products of the type of team and the number required of that respective type:

$$\begin{aligned} z_1 = \; & y_3y_8+y_4y_9 + y_5y_{10} + y_6y_{11} + y_7y_{12} + y_{13}y_{39} \\ & + y_{14}y_{59} + y_{15}y_{61} + y_{16}\, y_{60} + y_1y_{62} + y_2y_{63} \\ & + y_{55}y_{64} + y_{88}y_{89} \end{aligned} \qquad \text{(Eq. 1)}$$

Figure 3-1 shows the printout of the constituent parameters, y_k and the model of equation 1.

```
C********** Z(1) -- NUMBER OF PERSONNEL FOR FDD **********
C
      SUBROUTINE PERSON
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C   Z(1)   -- Number of personnel for FDD
C   Y(1)   -- Number of CMF's
C   Y(2)   -- Number of OB's
C   Y(3)   -- Number of multiple skill teams
C   Y(4)   -- Number of inspection teams
C   Y(5)   -- Number of AVE moving teams
C   Y(6)   -- Number of OSE R/R teams
C   Y(7)   -- Number of C**3/security repair teams
C   Y(8)   -- Number in multiple skill team
C   Y(9)   -- Number in inspection team
C   Y(10)  -- Number in AVE moving team
C   Y(11)  -- Number in OSE R/R team
C   Y(12)  -- Number in C**3/security repair team
C   Y(13)  -- Number of AVE R/R teams
C   Y(14)  -- Number of helicopters assigned to FDD
C   Y(15)  -- Number of vans assigned to FDD
C   Y(16)  -- Number of MSS
C   Y(39)  -- Number in AVE R/R team
C   Y(55)  -- Number of DAA's
C   Y(59)  -- Number in helicopter team
C   Y(60)  -- Number of personnel per MSS
C   Y(61)  -- Number in van team
C   Y(62)  -- Number of FDD personnel per CMF
C   Y(63)  -- Number of FDD personnel per OB
C   Y(64)  -- Number of FDD personnel per DAA
C   Y(88)  -- Number of security teams for FDD
C   Y(89)  -- Number in FDD security team
C
C   Assumption :
C
C   1. Skill level within a team will be taken into
C      account later.
C
      Z(1) = Y(3)*Y(8) + Y(4)*Y(9) + Y(5)*Y(10) + Y(6)*Y(11) +
     &       Y(7)*Y(12) + Y(13)*Y(39) + Y(14)*Y(59) + Y(15)*Y(61)
     &       + Y(16)*Y(60) + Y(1)*Y(62) + Y(2)*Y(63) + Y(55)*Y(64)
     &       + Y(88)*Y(89)
      RETURN
      END
```

Figure 3-1: z(1) Printout

3.2 FDD Equipment and Facility Cost, z_2

z_2 is defined as the sum of the costs of facilities and equipment for the CMF, OB, and DAA and is modelled as follows:

$$z_2 = y_1 y_{72} + y_2 y_{73} + y_{55} y_{74} + y_1 y_{75} + y_2 y_{76} + y_{55} y_{77} \qquad \text{(Eq. 2)}$$

Figure 3-2 shows the printout of the constituent parameters, y_k and the model of equation 2.

```
C********** Z(2) -- FDD EQUIPMENT AND FACILITIES COST **********
C
      SUBROUTINE EFCOST
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C   Z(2)   -- FDD equipment and facilities cost
C   Y(1)   -- Number of CMF's
C   Y(2)   -- Number of OB's
C   Y(55)  -- Number of DAA's
C   Y(72)  -- Cost of each CMF ($)
C   Y(73)  -- Cost of each OB ($)
C   Y(74)  -- Cost of each DAA ($)
C   Y(75)  -- Equipment cost per CMF ($)
C   Y(76)  -- Equipment cost per OB ($)
C   Y(77)  -- Equipment cost per DAA ($)
C
      Z(2) = Y(1)*Y(72)+Y(2)*Y(73)+Y(55)*Y(74)+Y(1)*Y(75)
     &       +Y(2)*Y(76)+Y(55)*Y(77)
      RETURN
      END
```

Figure 3-2: z(2) Printout

3.3 Task Time, z_3

The following assumptions were made for this model:

1. Launchable faults are handled whenever a no launch failure is acted on
2. Helicopters service a small proportion of AVE and OSE no-launch failures
3. Any maintenance action occurring on site or at the CMF is part of task time
4. Inspection of both AVE and OSE occurs during each action

Task time has been defined to be the time spent on removal and emplacement of TEL, inspection, remove/replace procedures, and entering/exiting site. Task time does not include any time covered by the submodel dispatch time; such as, travel, waiting, briefing, and delay times.

$$\begin{pmatrix}\text{Task}\\ \text{Time}\end{pmatrix} = \begin{pmatrix}\text{Removal}\\ \text{Time}\end{pmatrix} + \begin{pmatrix}\text{Remove/Replace}\\ \text{Procedures}\end{pmatrix} + \begin{pmatrix}\text{Inspection}\\ \text{Time}\end{pmatrix} + \begin{pmatrix}\text{Emplacement}\\ \text{Time}\end{pmatrix} + \begin{pmatrix}\text{Enter/Exit}\\ \text{Time}\end{pmatrix}$$

The definition of each of the above is:

Removal Time - Time spent in extracting the TEL from the PS (Protective Structure).

Remove/Replace Procedures - Time spent in removing a faulty LRU from the missile and replacing the LRU with a good unit. If there are any other repair type activities their times would be included here.

Inspection Time - Time taken to inspect, test, calibrate, adjust, etc. any part of the missile.

Emplacement Time - Time spent to replace the TEL along with good missile in the PS.

Enter/Exit Time - Time spent in entering and exiting the PS and its Perimeters.

The original modelling for this submodel began with the baseline concept of having AVE and OSE which could be separated from each other at the PS. This baseline was changed to removal and transport of both types of equipment to the CMF if a failure occured in either of the types of equipment. The original modeling was still found to be applicable to the new situation, except that the booster and reentry system was the old AVE and the MOSE/MGCS was the old OSE.

Inspection of both the booster/reentry systems and the MOSE/MGCS systems was assumed to occur whenever any type of corrective action was taken for any of the missile's subsystems. The elements used for inspection were y_{21} and y_{22}. The time to enter/exit a PS site was taken to be the same for all types of actions requiring site access and y_{94} was the designation used for this.

The failures of the missile had to be apportioned among the subsystems as they were expected to occur and affected following actions. This was done by use of the factor:

$$\frac{\left(\frac{\text{Number of No-Launch Booster}}{\text{Failures/Month}}\right) + \left(\frac{\text{Number of No-Launch R.S.}}{\text{Failures/Month}}\right)}{(\text{Number of Actions/Month})},$$

for booster and reentry failures (old AVE) and the factor:

$$\frac{\text{Number of No-Launch MOSE/MGCS Failures/Month}}{\text{(Number of Actions/Month}},$$

for MOSE/MGCS failures (old OSE).

Using the element designations results in:

$$\frac{y_{29} + y_{30}}{z_8} \quad \text{and} \quad \frac{y_{31}}{z_8}$$

for the booster/reentry systems and the MOSE/MGCS, respectively.

With the apportionment to the missile subsystems of removal, emplacement, and remove/replace times combined with inspection and enter/exit times the following resulted:

$$z_3 = \frac{y_{29} + y_{30}}{z_8} y_{50} + \frac{y_{31}}{z_8} y_{51}$$

(removal time)

$$+ \frac{y_{29} + y_{30}}{z_8} y_{23} + \frac{y_{31}}{z_8} y_{24}$$

(remove/replace procedures)

$$+ y_{21} + y_{22}$$

(inspection time)

$$+ \frac{y_{29} + y_{30}}{z_8} y_{19} + \frac{y_{31}}{z_8} y_{20}$$

(emplacement time)

$$+ y_{94}$$

(enter/exit time)

Combining and simplifying resulted in:

$$z_3 = \frac{y_{29} + y_{30}}{z_8}\left(y_{19} + y_{21} + y_{22} + y_{23} + y_{50} + y_{94}\right) \quad \text{(Eq. 3)}$$

$$+ \frac{y_{31}}{z_8}\left(y_{20} + y_{21} + y_{22} + y_{24} + y_{51} + y_{94}\right)$$

Figure 3-3 shows the printout of the constituent y_k and the Equation 3.

```
C********** Z(3) -- TASK TIME **********
C
      SUBROUTINE TASK
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C  Z(3)   -- Task time (minute)
C  Z(8)   -- Number of actions per month
C  Y(19) -- AVE emplacement time
C  Y(20) -- OSE emplacement time
C  Y(21) -- AVE inspection time
C  Y(22) -- OSE inspection time
C  Y(23) -- AVE repair time
C  Y(24) -- OSE repair time
C  Y(29) -- Number of booster no launch failures/month
C           per missile
C  Y(30) -- Number of RS no launch failures/month per
C           missile
C  Y(31) -- Number of MOSE/MGCS no launch failures/month
C  Y(35) -- Speed of helicopter (feet/minute)
C  Y(50) -- AVE removal time
C  Y(51) -- OSF removal time
C  Y(56) -- Distance between DAA and CMF (feet)
C  Y(65) -- Fraction of no-launch failures req. helicopter
C  Y(94) -- Time to ENTER/EXIT site
C
C  Assumption :
C  1.  Launchable faults are handled whenever a no
C      launch failure is acted on.
C  2.  Helicopter services a small proportion of AVE
C      and OSE no launch failures.
C  3.  Any maintenance action occuring on site or at
C      the CMF is part of task time.
C  4.  Inspection of both AVE and OSE occurs during
C      each action.
C
      Z(3) = (Y(29)+Y(30))/Z(8) * (Y(19)+Y(21)+Y(22)
     &       +Y(23)+Y(50)+Y(94)) + Y(31)/Z(8)*
     &       (Y(20)+Y(21)+Y(22)+Y(24)+Y(51)+Y(94))
      RETURN
      END
```

Figure 3-3:   z(3) Printout

3.4 Dispatch Time, z_4

Dispatch time was defined as the time spent on travelling, briefing, or waiting; from fault detection to end of no launch status.

$$\begin{pmatrix}\text{Dispatch}\\ \text{Time}\end{pmatrix} = \begin{pmatrix}\text{Travel}\\ \text{Time}\end{pmatrix} + \begin{pmatrix}\text{Waiting}\\ \text{Time}\end{pmatrix} + \begin{pmatrix}\text{Briefing}\\ \text{Time}\end{pmatrix}$$

Briefing time is assumed constant at 30 minutes. Travel time is composed of any time spent travelling between DAA and CMF, CMF and PS, and PS for the shell game of SALT Verification.

The time for a crew to travel by van from the DAA to the CMF is:

$$\begin{pmatrix}\text{Time From}\\ \text{DAA to CMF}\\ \text{for Van}\end{pmatrix} = \frac{\begin{pmatrix}\text{Distance between}\\ \text{DAA and CMF}\end{pmatrix}}{\text{Speed of Van}} = \frac{y_{56}}{y_{37}}$$

The time spent for retrieving and transporting the missile while covered by the MSS is composed of the time to pick up the down missile, the time to transport it back to the CMF, and the time to get it back to the PS once repaired. Therefore, there are three trips between the CMF and PS with the MSS:

$$\begin{pmatrix}\text{Time between}\\ \text{CMF \& PS}\end{pmatrix} = \frac{\begin{pmatrix}\text{Three trips until}\\ \text{End of N-L Status}\end{pmatrix}\begin{pmatrix}\text{Distance between}\\ \text{CMF and PS}\end{pmatrix}}{(\text{Speed of MSS})} = \frac{y_{58}}{y_{36}}$$

There is time spent travelling between PS for maintaining PLU and emplacing the good missile in a PS on a random basis. All PS are visited on the retrieval trip. With 23 PS there are 22 trips between PS on the retrieval of the down missile. With an equal random chance that the good missile will be placed at a given PS, the average number of trips between

PS is 22 divide by 2 or 11. Therefore, the total average number of trips between PS is 33.

$$\begin{pmatrix}\text{Time between}\\ \text{PS for PLU}\end{pmatrix} = \frac{\begin{pmatrix}\text{33 Trips between PS}\\ \text{until end of N-L status}\end{pmatrix}\begin{pmatrix}\text{Distance}\\ \text{between PS}\end{pmatrix}}{(\text{Speed of MSS})} = \frac{y_{18}}{y_{36}}$$

On some occasions the need for an extra part, equipment, or personnel to be transported to the CMF may arise because of unforeseen occurrences or needs at the cluster. It is assumed that a helicopter will be used when this need for extra parts, equipment, or personnel develops. This time spent transporting any of the above items to the cluster needs to be included in travel time.

$$\begin{pmatrix}\text{Time between DAA \& CMF}\\ \text{for fraction of time}\\ \text{helicopter is used}\end{pmatrix} = \frac{\begin{pmatrix}\text{Fraction of}\\ \text{actions heli-}\\ \text{copter is used}\end{pmatrix}\begin{pmatrix}\text{Distance}\\ \text{between}\\ \text{DAA \& CMF}\end{pmatrix}}{(\text{Speed of helicopter})} = \frac{y_{65}y_{56}}{y_{35}}$$

Combining all the travel times results in:

$$\begin{pmatrix}\text{Travel}\\ \text{Time}\end{pmatrix} = \frac{y_{56}}{y_{37}} + \frac{3[y_{58} + 11y_{18}]}{y_{36}} + \frac{y_{65}y_{56}}{y_{35}}$$

Waiting time as modeled is composed of time waiting for Strategic Arms Limitation Verification and any delay not covered by SALVER, travel times, or briefing.

The wait for SALVER occurs at least once per year for each missile or whenever the cluster barrier is removed. This removal is necessary when a booster or reentry system fails, because the down missile has

to be replaced by a good missile. Since the modeling is for one missile the proportion of the booster and reentry system failures out of the total failures that occur for one missile is needed. This proportion is:

$$\frac{\begin{pmatrix}\text{\#Booster N-L} \\ \text{failures/mon.}\end{pmatrix} + \begin{pmatrix}\text{\#R.S. N-L} \\ \text{failures/mon.}\end{pmatrix}}{(\text{Total \# N-L failures/mon})} = \frac{y_{29} + y_{30}}{z_8}$$

Where z_8 is the submodel of the total number of no-launch failures per month for one missile.

When the barrier is removed the total time spent for SALVER is four days; expressed in minutes in this model. This results in the following:

$$\frac{y_{29} + y_{30}}{z_8}(4\times 24\times 60)$$

Since this modeling is on the basis of one missile a method is to add SALVER if the barrier was removed less than once per year per missile for repair operations.

If the total number of failures that requires barrier removal is less than once per year or in this model 1/12 per month, the total has to be increased to the needed 1/12 per month. This is done by the following factor:

$$\phi\left[\frac{1}{12} - \left\{\begin{pmatrix}\text{\#Booster N-L} \\ \text{failures/mon}\end{pmatrix} + \begin{pmatrix}\text{\#RS N-L} \\ \text{failures/mon}\end{pmatrix}\right\}\right] \quad (4\times 24\times 60)$$

or in terms of parameters:

$$y_{92}\left[\frac{1}{12} - [y_{29} + y_{30}]\right] \quad (4\times 24\times 60)$$

The ϕ or y_{92} being 1 if $[y_{29} + y_{30}]$ is less than $\frac{1}{12}$ and 0 if equal to or greater than $\frac{1}{12}$. The factor 4x24x60 is the 4 day SALVER in minutes.

The remaining item contributing to waiting time is any other delay which is not handled elsewhere. An example would be delay to start operations until the next shift or daylight. If there is a probability distribution associated with these delays it is assumed that the expected value is used. The element representing delay is y_{52}. Another item of delay which has its own element designation is delay on each of the 33 trips for PLU purposes when each PS is visited to check up or leave a missile. This element is y_{93}.

All of these waiting times and delays combine to give

$$\binom{\text{Waiting}}{\text{Time}} = \left[\frac{y_{29} + y_{30}}{z_8} + y_{92}\left[\frac{1}{12} - y_{29} - y_{30}\right]\right](4\text{x}24\text{x}60)$$

$$+ y_{52} + 33y_{93}$$

The complete submodel for Dispatch Time including travel times, briefing time, and wait times is:

$$z_4 = \frac{3}{y_{36}}\left[y_{58} + 11y_{18} + 11y_{93}\right] + 5760\,\frac{y_{29} + y_{30}}{z_8}$$

$$+ y_{92}\left[(\frac{1}{12} - y_{29} - y_{30})\right] + \frac{y_{56}}{y_{37}}$$

$$+ \frac{y_{56}y_{65}}{y_{35}} + y_{52} + 30; \qquad \text{(Eq. 4)}$$

Figure 3-4 shows the printout for z_4, listing the parameter major assumptions, constants, and a Fortran listing of Eq. 4.

```
C********** Z(4) -- DISPATCH TIME **********
C
      SUBROUTINE DISPCH
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C   Z(4)    -- Dispatch time (minute)
C   Y(18)  -- Distance between PS (feet)
C   Y(29)  -- Number of booster no launch failures/month
C              per missile
C   Y(30)  -- Number of RS no launch failures/month per
C              missile
C   Y(35)  -- Speed of helicopter (feet/minute)
C   Y(36)  -- Speed of MSS (feet/minute)
C   Y(37)  -- Speed of van (feet/minute)
C   Y(52)  -- Delay (minute)
C   Y(56)  -- Distance between DAA and CMF
C   Y(58)  -- Distance between CMF and PS
C   Y(65)  -- Fraction of no-launch failures req. helicopter
C   Y(92)  -- SAL verifications (at least once per year)
C   Y(93)  -- Time spent at each PS for PLU (minute)
C
C   Assumption :
C   1.   AVE equipment is composed of booster and reentry
C        system.
C   2.   OSE equipment is MOSE/MGCS.
C   3.   Van transports team and any spares or equipment
C        to CMF.
C   4.   There is one MSS per cluster which implies that
C        if the MSS fails then the barrier has to be
C        opened.
C   5.   LRU R/R is not allowed at the PS.
C   6.   Y(92) = 1,if Y(29)+Y(30) is greater than 1./12.;
C        0 otherwise.
C
C   Constants used :
C   4 days of waiting time for salver & closure of portholes
C   -- 4.*24.*60. minutes
C   Number of CMF-PS trips -- 3.
C   Average number of trips between PS, for shell game, in
C   retrieving and installing a missile -- 33.
C   Briefing time -- 30. minutes
C
      Z(4) = 3./Y(36)*(Y(58)+11.*(Y(18)+Y(93))) +
     *        5760.*(Y(29)+Y(30))/Z(8) + Y(92)*(1./12.-
     *        Y(29)-Y(30)) + Y(56)/Y(37) + Y(56)*Y(65)
     *        /Y(35) + Y(52) + 30.
      RETURN
      END
```

Figure 3-4: z(4) Printout

3.5 FDD Personnel Cost, z_5

FDD activities are performed by specialty teams which vary in size and composition according to the task to be performed. The type of teams, their numbers and costs have been defined as:

	Parameter	Cost Per Team
- Multiple skill team	y_3	y_{45}
- Inspection team	y_4	y_{47}
- OSE remove/replace team	y_6	y_{43}
- AVE remove/replace team	y_{13}	y_{44}
- C^3 security repair team	y_7	y_{48}
- ROSE repair team	y_{38}	y_{49}
- AVE/OSE moving team	y_{57}	y_{46}
- Crane team	y_{82}	y_{91}
- Helicopter team	y_{86}	y_{27}
- Security team	y_{88}	y_{90}
- Van teams	y_{87}	y_{28}

By multiplying these number of teams by their respective cost per team the total cost of teams for a candidate system is evaluated.

To the team cost is added the cost for FDD personnel stationed in each CMF, OB, and DAA. They are identified as follows:

	Parameter	Average Pay
- FDD personnel per CMF	y_{62}	y_{68}
- FDD personnel per OB	y_{63}	y_{69}
- FDD personnel per DAA	y_{64}	y_{70}

By multiplying the above costs by the number of CMF, OB, and DAA (i.e., y_1, y_2,y_{55}) the FDD personnel cost not associated with a team is obtained. Adding yields z_5:

$$
\begin{aligned}
z_5 = (1.33)(6.7101) \Big[& y_{46}y_{57} + y_3y_{45} + y_4y_{47} \\
& + y_6y_{43} + y_7y_{48} + y_{13}y_{44} + y_{38}y_{49} \\
& + y_{86}y_{27} + y_{28}y_{87} + y_1y_{62}y_{68} + y_2y_{63}y_{69} \\
& + y_{55}y_{64}y_{70} + y_{88}y_{90} + y_{82}y_{91} + y_{26}\Big] \; ; \qquad \text{(Eq. 5)}
\end{aligned}
$$

z_5 is adjusted by the manning factor of 1.33 and further assumes an MX life span of 10 years. Therefore, an equal payment series present worth factor is 6.7101. The parameter y_{26} is defined as the base operating support cost that incorporates general costs not directly associated with FDD but required to support FDD activities.

Figure 3.5 shows the computer listing for z_5 including the Fortran version of equation 5.

```
C********** Z(5) -- FDD PERSONNEL COST **********
C
      SUBROUTINF PC3ST
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C  Z(5)   -- FDD personnel cost
C  Y(1)   -- Number of CMF's
C  Y(2)   -- Number of OB's
C  Y(3)   -- Number of multiple skill teams
C  Y(4)   -- Number of inspection teams
C  Y(6)   -- Number of OSE R/R teams
C  Y(7)   -- Number of C**3/security repair teams
C  Y(13)  -- Number of AVE R/R teams
C  Y(26)  -- Base operating support cost ($)
C  Y(27)  -- Personnel cost/helicopter team ($)
C  Y(28)  -- Personnel cost/van team ($)
C  Y(38)  -- Number of ROSE repair teams
C  Y(43)  -- Personnel cost/OSE R/R team
C  Y(44)  -- Personnel cost/AVE R/R team
C  Y(45)  -- Personnel cost/multiple skill team
C  Y(46)  -- Personnel cost per AVE/OSE moving team
C  Y(47)  -- Personnel cost/inspection team
C  Y(48)  -- Personnel cost/C**3 - security repair team
C  Y(49)  -- Personnel cost/ROSE repair team
C  Y(55)  -- Number of DAA's
C  Y(57)  -- Number of AVE/OSE moving teams
C  Y(62)  -- Number of FDD personnel per CMF
C  Y(63)  -- Number of FDD personnel per OB
C  Y(64)  -- Number of FDD personnel per DAA
C  Y(68)  -- Average pay for CMF personnel ($)
C  Y(69)  -- Average pay for OB personnel ($)
C  Y(70)  -- Average pay for DAA personnel ($)
C  Y(82)  -- Number of crane teams
C  Y(86)  -- Number of helicopter teams
C  Y(87)  -- Number of van teams
C  Y(88)  -- Number of security teams
C  Y(90)  -- Personnel cost/FDD
C  Y(91)  -- Personnel cost/crane team
C
C  CONSTANT USED :
C
C  10 Years -- Life span of MX program once developed.
C  1.33     -- Manning factor for 75% use of personnel.
C  6.7101   -- Present value of an annual expense for 10
C              years at 8 % per year compounded annually.
C
      Z(5) = (1.33*(Y(46)*Y(57) + Y(3)*Y(45) + Y(4)*Y(47)
     &       + Y(6)*Y(43) + Y(7)*Y(48) + Y(13)*Y(44)
     &       + Y(26) + Y(38)*Y(49) + Y(86)*Y(27) +
     &       Y(28)*Y(87) + Y(1)*Y(62)*Y(68) +
     &       Y(2)*Y(63)*Y(69) + Y(55)*Y(64)*Y(70) + Y(88)*
     &       Y(90) + Y(82)*Y(91))*10.)*6.7101
      RETURN
      END
```

Figure 3-5: z(5) Printout

3.6 FDD Vehicle Cost, z_6

This submodel computes the cost of vehicles assigned to FDD at each CMF, OB, and DAA. The type of vehicles, their numbers and costs are represented as follows:

	Identification	Costs
Helicopters	y_{14}	y_{42}
Vans	y_{15}	y_{40}
MSS	y_{16}	y_{41}
STV	y_{53}	y_{71}
Cranes	y_{81}	y_{85}

This vehicle cost for a given candidate system is:

$$z_6 = y_{14}y_{42} + y_{15}y_{40} + y_{16}y_{41}$$

$$+ y_{53}y_{71} + y_{17}y_{81}y_{85} \; ; \qquad \text{(Eq. 6)}$$

Figure 3-6 shows the computer listing for z_6 and equation 6.

```
C********** Z(6) -- FDD VEHICLE COST **********
C
      SUBROUTINE VCOST
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C  Z(6)   -- FDD vehicle cost
C  Y(14) -- Number of helicopters assigned to FDD
C  Y(15) -- Number of vans assigned to FDD
C  Y(16) -- Number of MSS's
C  Y(17) -- Number of clusters
C  Y(40) -- Cost per van ($)
C  Y(41) -- Cost per MSS ($)
C  Y(42) -- Cost per helicopter ($)
C  Y(53) -- Number of STV's
C  Y(71) -- Cost per STV ($)
C  Y(81) -- Number of cranes per cluster
C  Y(85) -- Cost per crane ($)
C
      Z(6) = Y(14)*Y(42) + Y(15)*Y(40) + Y(16)*Y(41)
     &        + Y(53)*Y(71) + Y(17)*Y(81)*Y(85)
      RETURN
      END
```

Figure 3-6: z(6) Printout

3.7 FDD Operating and Spares Costs, z_7

This submodel computes the inventory cost associated with each CMF, OB, and DAA. Their symbols are:

y_{78} - Inventory cost per CMF

y_{79} - Inventory cost per OB

y_{80} - Inventory cost per DAA

The FDD operating and spares costs for a given candidate system is obtained by multiplying these costs by the respective number of CMF, OB, or DAA:

$$z_7 = y_1 y_{78} + y_2 y_{79} + y_{55} y_{80} \qquad \text{(Eq. 7)}$$

Figure 3-7 shows the computer listing for z_7.

```
C********** Z(7) -- FDD OPERATING AND SPARE COST **********
C
      SUBROUTINE OSCOST
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C  Z(7)  -- FDD operating and spare cost
C  Y(1)  -- Number of CMF's
C  Y(2)  -- Number of OB's
C  Y(55) -- Number of DAA's
C  Y(78) -- Inventory cost per CMF ($)
C  Y(79) -- Inventory cost per OB ($)
C  Y(80) -- Inventory cost per DAA ($)
C
      Z(7) = Y(1)*Y(78) + Y(2)*Y(79) + Y(55)*Y(80)
      RETURN
      END
```

Figure 3-7: z(7) Printout

3.8 Number of Actions per Month, z_8

This submodel is defined as the total number of no-launch failures per month for one missile. The missile subsystems were divided into booster, reentry system, and MOSE/MGSC subsystems. Hence:

Number of Actions/Month = Number of no-launch booster failures/month
+ Number of no-launch R.S. failures/month
+ Number of no-launch MOSE/MGCS failures/month

or:

$$z_8 = y_{29} + y_{30} + y_{31} \qquad \text{(Eq. 8)}$$

Figure 3-8 shows the computer listing for z_8

```
C*********** Z(8) -- NUMBER OF ACTIONS PER MONTH **********
C
      SUBROUTINE ACTION
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C   Z(8)   -- Number of actions per month
C   Y(29) -- Number of booster no launch failures/month per
C             missile
C   Y(30) -- Number of RS no launch failures/month per missile
C   Y(31) -- Number of MOSE/MGCS no launch failures/month per
C             missile
C
C   Assumption :
C
C   1. Launchable faults are handled only when
C      no launch failures are acted upon.
C
      Z(8) = Y(29) + Y(30) + Y(31)
      RETURN
      END
```

Figure 3-8: z(8) Printout

4.0 CRITERION MODELS

Section 2.4 identified the criteria to be used for evaluation of candidate system performance as well as the relative importance of each criterion. The sections below develop each criterion model.

4.1 Preservation of Location Uncertainty (PLU), x_1

PLU is defined to be the indicator of location uncertainty retention or non-degredation. It was decided that PLU was related to the number of FDD personnel, other personnel who had to know missile locations, the time of maintenance actions (task time and dispatch time), and time of deceptive actions.

As the number of FDD personnel increases, the number of ways that personnel can be used to reduce the fraction who are aware of missile location increases, hence achieving better levels of PLU. However, the increase in the number of personnel knowing missile locations decreases PLU because of the increase in interaction among the personnel. The longer and more frequent maintenance activity requires increased exposure time so that detection of anomalies becomes easier by unfriendly forces.

To handle the personnel factors:

$$\frac{\text{(Number of personnel for FDD)}}{\begin{pmatrix}\text{Number of maintenance}\\ \text{personnel knowing}\\ \text{missile locations}\end{pmatrix} + \begin{pmatrix}\text{Number of CAMMS}\\ \text{personnel who need}\\ \text{to know missile location}\end{pmatrix}} = \frac{z_1}{y_{25}+y_{66}}$$

where y_{25} is derived from the product of the number of teams that may

know a missile location by the number of personnel in each team. This is:

$$y_{25} = y_3 y_8 + y_5 y_{10} + y_6 y_{11} + y_{16} y_{60} + y_{88} y_{89}$$

(Note that this factor is dimensionless).

Maintenance times are:

$$\frac{\text{Total Time}}{\begin{pmatrix}\text{Number of}\\ \text{Actions/Month}\end{pmatrix}\begin{pmatrix}\text{Task} \\ \text{Time} \end{pmatrix} + \begin{pmatrix}\text{Dispatch}\\ \text{Time}\end{pmatrix}} = \frac{43200}{z_8\left(z_3 + z_4\right)}$$

Summing the personnel factor and the maintenance factor provides a PLU index which is x_1:

$$x_1 = \frac{z_1}{y_{25} + y_{66}} + \frac{43200}{z_8\left(z_3 + z_4\right)} ; \qquad \text{(Eq. 9)}$$

Figure 4-1 shows the computer listing, x_1

```
C********** X(1) -- PRESERVATION OF LOCATION UNCERTAINTY **********
C
      SUBROUTINE PLU
C
      COMMON DEVICE,X(5),Y(150),Z(20)
C
C  X(1)   -- Preservation of location uncertainty
C  Z(1)   -- Number of personnel for FDD
C  Z(3)   -- Task time (minute)
C  Z(4)   -- Dispatch time (minute)
C  Z(8)   -- Number of actions per month
C  Y(25)  -- Number of maintenance personnel knowing missile(s)
C            location(s)
C  Y(66)  -- Number of personnel at CAMMS need to know missile(s)
C            location(s)
C
C  TOTAL -- Total number of minutes in 30 days
C
      TOTAL = 43200.0
      X(1) = Z(1)/((Y(25)+Y(66)) + TOTAL/(Z(8)
     &      *(Z(3)+Z(4)))
      RETURN
      END
```

II. Assumption :

1. Launchable faults are handled only when no launch faults are acted upon.
2. Y(25) = Y(3)*Y(8) + Y(5)*Y(10) + Y(6)*Y(11) + Y(16)*Y(60) + Y(88)*Y(89)
   This is the number of FDD maintenance personnel that may directly know the location of one or more missiles.
3. Skill level within a team will be taken into account later.

Figure 4-1: x(1) Printout

4.2 Availability x_2

Availability is defined as the fraction of up time divided by the total time and was modeled as the total time minus the down time divided by the total time (the fraction of downtime).

$$\text{Availability} = \frac{(\text{Total Time}) - (\text{Down Time})}{(\text{Total Time})}$$

This availability model is based upon one months time in minutes and for one missile. "Up time" is defined as time that the missile is launchable to a hard or soft target.

Down time is seen as being composed of time spent on any maintenance task or time spent by crews on other duties not directly involved in tasks, called "dispatch time". The number of actions in one month time for one missile is also needed.

The definition and structuring of task time z_3, dispatch time z_4, and number of actions/month, z_8, submodels are given in the submodel development sections (3.3., 3.4, 3.8).

Using the above items and their designations, availability is:

$$x_2 = \frac{\left(\text{Total Time}\right) - \left(\frac{\text{Number of Actions}}{\text{Month}}\right)\left(\begin{matrix}\text{Dispatch}\\ \text{Time}\end{matrix} + \begin{matrix}\text{Task}\\ \text{Time}\end{matrix}\right)}{(\text{Total Time})}$$

$$= \frac{\text{Total} - z_8(z_4 + z_3)}{\text{Total}}; \quad \text{Total} = 43{,}200 \text{ minutes}$$

Using the submodels as previously structured gives:

$$
\begin{aligned}
x_2 = \frac{1}{43,200} \Big[& 43,200 - (y_{29} + y_{30})(y_{50} + y_{23} + y_{19} + 5760) \\
& - y_{31}(y_{51} + y_{24} + y_{20}) \\
& - (y_{29} + y_{30} + y_{31}) \Big\{ \frac{3}{y_{36}}(y_{58} + 11y_{18} + 11y_{93}) \\
& \quad + 5760\, y_{92} \left(\frac{1}{12} - y_{29} - y_{30}\right) + \frac{y_{56}}{y_{37}} \\
& \quad + \frac{y_{56}y_{65}}{y_{35}} + y_{52} + y_{21} + y_{22} + y_{94} + 30 \Big\} \Big] \qquad \text{(Eq. 10)}
\end{aligned}
$$

Figure 4-2 shows the computer listing for x_2

```
C********** X(2) -- AVAILABILITY **********
C
      SUBROUTINE AVAIL
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C  X(2) -- Availability
C  Z(3) -- Task time (minute)
C  Z(4) -- Dispatch time (minute)
C  Z(8) -- Number of actions per month
C
C  Assumptions :
C  1. A missile is launchable (available) if it can be
C     targeted and launched to either a hard or soft target.
C  2. This availability is modeled for one missile.
C  3. Total time is figured on a 30-day month.
C
C  TOTAL -- Total number of minutes in 30 days
C
      TOTAL = 43200.0
      X(2) = (TOTAL - Z(8)*(Z(4)+Z(3)))/TOTAL
      RETURN
      END
```

II. Assumption :

1. A missile is launchable (available) if it can be targeted and launched to either a hard or soft target.
2. This availability is modeled for one missile.
3. Total time is figured on a 30-day month.
4. Launchable faults are handled only when a no launch failure is acted on.
5. Helicopter services a small proportion of AVE and OSE no-launch failures.
6. Any maintenance action occuring on site or at the CMF is part of task time.
7. AVE equipment is composed of booster and reentry system.
8. OSE equipment is MOSE/MGCS.
9. Van transports team and any spares or equipment to CMF.
10. There is one MSS per cluster which implies that if the MSS fails then the barrier has to be opened.
11. LRU R/R is not allowed at the PS.
12. Y(92)=1;if Y(29)+Y(30) is greater than 1/12; otherwise 0.
13. Inspection of both AVE and OSE occurs during each action.

Figure 4-2: x(2) Printout

4.3 Comparative Costs, x_3

This criterion estimates the effect of candidate system cost and is measured in dollars and defined in terms of four submodels:

z_2 FDD equipment and facility costs

z_5 FDD personnel cost

z_6 FDD vehicle cost

z_7 FDD operating and spare cost

Comparative cost, x_3, is defined as the sum of these submodels, hence:

$$x_3 = -(z_2 + z_5 + z_6 + z_7) \quad \text{(Eq. 11)}$$

Figure 4-3 shows the computer listing for this criterion.

```
C********** X(3) -- COST **********
C
      SUBROUTINE COST
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C  X(3) -- Cost
C  Z(2) -- FDD equipment and facilities cost ($)
C  Z(5) -- FDD personnel cost ($)
C  Z(6) -- FDD vehicle cost ($)
C  Z(7) -- FDD operating and spare cost ($)
C
      X(3) =-Z(2)-Z(5)-Z(6)-Z(7)
      RETURN
      END
```

II. Assumption :

1. The cost derived by X(3) is only for comparative purposes among candidate systems.
2. Cost of vehicles includes cost of equipment that is assigned to the vehicle for FDD purposes.
3. Vehicle and facility life are 10 years.
4. Personnel at facilities does not include hands-on operational personnel.
5. Average pay is a weighted average of civilian, officer and airman pay.
6. Life of MX program is 10 years.
7. Value of money is 8% per year for the 10-year period.

Figure 4-3: x(3) Printout

4.4 Team Utilization, x_4

The criterion, Team Utilization is defined as the ratio of total team hours used to total team hours available. This is modelled as the ratio of total team minutes used to total team minutes available. The teams are "used" in task action and in dispatch action.

The number of actions per month is obtained from z_8, task time from z_3, and dispatch time from z_4. The basic model of x_4 is:

$$\frac{\begin{pmatrix}\text{Number of}\\\text{Actions}\end{pmatrix}\left[\begin{pmatrix}\text{Dispatch}\\\text{Time}\end{pmatrix}+\begin{pmatrix}\text{Task}\\\text{Time}\end{pmatrix}-\begin{pmatrix}\text{Dispatch Time}\\\text{Correction}\end{pmatrix}\right]}{(\text{Total average team-minutes})}$$

Total average team minutes is:

(9 team types)(30 days/mon)(8 hours/day)(60 min/hour)(1.33 manning factor) = 172,368

The dispatch time correction includes correction for SALT verification, delay, trip back to DAA (or OB), and the 11 extra trips and waiting at PS. This factor is:

$$- y_{92}\left(y_{29} + y_{30} - \frac{1}{12}\right)(4\times24\times60) - \frac{4\times24\times60}{12}$$

$$+ \frac{y_{56}}{y_{37}} - y_{52} + 11\left(\frac{y_{18}}{y_{36}} + y_{93}\right)$$

Combining, the model for x_4, Team Utilization is:

$$x_4 = \frac{z_8}{172,368}\left[z_4 - y_{92}\left(y_{29} + y_{30} - \frac{1}{12}\right)(4\times24\times60) - \frac{4\times24\times60}{12} + \frac{y_{56}}{y_{37}} - y_{52} + 11\left(\frac{y_{18}}{y_{36}} + y_{93}\right) + z_3\right] ; \text{(Eq. 12)}$$

Figure 4-4 shows the computer print-out of this model.

```
C********** X(4) -- TEAM UTILIZATION **********
C
      SUBROUTINE UTILIZ
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C   X(4)   -- Team utilization
C   Z(3)   -- Task time (minute)
C   Z(4)   -- Dispatch time (minute)
C   Z(8)   -- Number of actions per month
C   Y(18) -- Distance between PS (feet)
C   Y(29) -- Number of booster no launch failures/month per
C             missile
C   Y(30) -- Number of RS no launch failures/month per missile
C   Y(36) -- Speed of MSS (feet/minute)
C   Y(37) -- Speed of van (feet/minute)
C   Y(52) -- Delay (minute)
C   Y(56) -- Distance between DAA and CMF
C   Y(92) -- SAL verifications (at least once per year)
C   Y(93) -- Time spent at each PS for PLU (minute)
C
      X(4) = Z(8)*(Z(4)-Y(92)*(Y(29)+Y(30)-1./12.)*4.*24.*60.
     &       -4.*24.*60./12.+Y(56)/Y(37)-Y(52)+11.*Y(18)/Y(36)
     &       +11.*Y(93)+Z(3))/(9.*30.*8.*60.*1.33)
      RETURN
      END
```

Figure 4-4: x(4) Printout

Assumptio, 'Next Page)

II. Assumption :

1. FDD support personnel at facilities are assumed productive when on duty.
2. ROSE failures do not cause team action because they are taken care of while attending to the no launch failures.
3. A shift consists of 8 hours.
4. A month consists of 30 working days.
5. Launchable faults are assumed to be handled while attending to the no launch failures.
6. Manning factor is 0.75
7. Helicopter services a small proportion of AVE and OSE no launch failures.
8. Any maintenance action occuring on site or at the CMF is part of task time.
9. Inspection of both AVE and OSE occurs during each action.
10. AVE equipment is composed of booster and reentry system.
11. OSE equipment is MOSE/MGCS.
12. Van transports team and any spares or equipment to CMF.
13. There is one MSS per cluster which implies that the MSS fails then the barrier has to be opened.
14. LRU R/R is not allowed at the PS.
15. Y(92)=1, if Y(29)+Y(30) is greater than 1./12.; 0 otherwise.
16. Daylight (1 shift) operation is assumed.
17. Modeling is for an average team representing all maintenance teams.
18. Waits during which teams can be used elsewhere are excluded from time team is considered productively utilized.

Figure 4-4: x(4) Printout (Continued)

4.5 Vehicle and Equipment Utilization, x_5

Vehicle and Equipment (V & E) Utilization is defined as the following ratio:

$$\frac{\text{(Total number of V \& E minutes used)}}{\text{(Total number of V \& E minutes possible)}}$$

V & E are considered utilized when:

1. maintenance teams use them
2. transport of missile to/from DAA
3. SALVER procedures

The total STV trip time for a replacement missile is:

$$\frac{4y_{56}\left(y_{29} + y_{30}\right)}{y_{54}}$$

Team utilization factor relating V & E use is:

$$\frac{(9)(1.33)x_4}{3(y_{14} + y_{15} + y_{16} + y_{53})}$$

Where 9 is the number of different teams, 1.33 is the manning factor and 3 is the number of shifts.

MSS use not included in team utilization is:

$$z_8\left(\frac{44\ y_{18} + 4y_{58}}{y_{36}}\right)$$

The possible V & E usable time is

$$60 \times 8 \times 3 \times 30\ (y_{14} + y_{15} + y_{16} + y_{53})$$

Combining for the total missile:

$$x_5 = y_{17} \left[4 \left(y_{29} + y_{30} \right) \frac{y_{56}}{y_{54}} + \frac{9 \times 1.33\ x_4}{3(y_{14} + y_{15} + y_{16} + y_{53})} \right.$$

$$\left. + z_8 \left(\frac{44y_{18} + 4y_{58}}{y_{36}} \right) \right] \left[\frac{1}{60 \times 8 \times 3 \times 30(y_{14}+y_{15}+y_{16}+y_{53})} \right]; \quad \text{(Eq. 13)}$$

Figure 4-5 shows the computer listing of this model.

```
C********** X(5) -- VEHICLE AND EQUIPMENT UTILIZATION **********
C
      SUBROUTINE VEUTIL
C
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C   X(4)   -- Team utilization
C   X(5)   -- Vehicle and equipment utilization
C   Z(8)   -- Number of actions per month
C   Y(14)  -- Number of helicopters assigned to FDD
C   Y(15)  -- Number of vans assigned to FDD
C   Y(16)  -- Number of MSS's
C   Y(17)  -- Number of clusters
C   Y(18)  -- Distance between PS (feet)
C   Y(29)  -- Number of booster no launch failures/month
C             per missile
C   Y(30)  -- Number of RS no launch failures/month per
C             missile
C   Y(35)  -- Speed of helicopter (feet/minute)
C   Y(36)  -- Speed of MSS (feet/minute)
C   Y(37)  -- Speed of van (feet/minute)
C   Y(52)  -- Delay (minute)
C   Y(53)  -- Number of STV's
C   Y(54)  -- Speed of STV
C   Y(56)  -- Distance between DAA and CMF
C   Y(58)  -- Distance between CMF and PS
C   Y(65)  -- Fraction of no launch failures req. helicopter
C   Y(92)  -- SAL verifications (at least once per year)
C
      X(5) = Y(17)*(4.*(Y(29)+Y(30))*Y(56)/Y(54) +
     &       (X(4)*9.*1.33/(3.*(Y(14)+Y(15)+
     &       Y(16)+Y(53)))) + Z(8)*(44.*Y(18)/
     &       Y(36)+4.*Y(58)/Y(36)))/(50.*8.*
     &       3.*30.*(Y(14)+Y(15)+Y(16)+Y(53)))
      RETURN
      END
```

II. Assumption :

1. MSS and van are used during the task time.
2. There are 2 shifts per day.
3. MOSE has 3 shifts of 8 hours each.
4. Vehicle utilization is evaluated on a per missile basis.
5. Missile canister is not switched from one STV to another.
6. Launchable faults are handled whenever a no launch failure is acted on.
7. Helicopter services a small proportion of AVE and OSE no launch failures.
8. Any maintenance action occuring on site or at the CMF is part of task time.
9. Inspection of both AVE and OSE occurs during each action.

Figure 4-5: x(5) Printout

4.6 SAL Verification, x_6

The definition established for SALVER is: - the probability that SALT verification activities will be accomplished in the specified period of time, given the number of cranes available, the minimum number of cranes needed,and the reliability of a crane for a SALVER cycle.

This definition and the resulting model is deemed appropriate because the opening and closure of the SAL ports at the PS has the longest time line.

The binomial distribution is used to obtain the desired probability and was based upon the fact that a crane is either in a failed or non-*failed state for* SALVER operations, the probability that an individual crane would survive the SALVER cycle was obtainable and assumed the same for all cranes, and there would always be at least the minimum number of cranes needed physically obtainable for each cluster of P.S.

The binomial equation to derive the probability of successful SALVER completion using w for the number of cranes per cluster, p for the seven-day crane reliability, and m for the minimum number of cranes needed per cluster is:

$$\sum_{r=m}^{w} \binom{w}{p} p^r (1-p)^{w-r}$$

Substituting p and w by their corresponding parameters:

$$\sum_{r=y_{84}}^{y_{81}} \binom{y_{81}}{r} y_{83}^r (1 - y_{83})^{y_{81} - r}$$

Where $\binom{y_{81}}{r}$ is the number of combinations of y_{81} taken r at a time. For computational purposes define a variable k as $k = r - y_{84}$, then

$r = k + y_{84}$ and substituting above:

$$x_5 = \sum_{k=o}^{y_{81} - y_{84}} \binom{y_{81}}{y_{84}+k} y_{83}^{\,y_{84}+k} \left(1 - y_{83}\right)^{y_{81}-y_{84}-k} \quad ; \text{(Eq. 14)}$$

Where: $$\binom{y_{81}}{y_{84}+k} = \frac{y_{81}!}{(y_{84}+k)!\,(y_{81}-y_{84}-k)!}$$

Figure 4-6 shows the computer listing of this model.

```
C********** X(6) -- SAL VERIFICATION **********
C
      SUBROUTINE SAL
      COMMON DEVICE,X(6),Y(150),Z(20)
C
C  X(6)   -- SAL verification
C  Y(81) -- Number of cranes/cluster
C  Y(83) -- SEVEN-DAY crane reliability
C  Y(84) -- Minimum number of cranes needed per cluster
C
      SUM = 0.0
      N = (Y(81) - Y(84)) + 1
      DO 10 I = 1,N
      II = I-1
      SUM = SUM + IFACT(IFIX(Y(81)))/(IFACT(IFIX(Y(84)+II))*
     &       IFACT(IFIX(Y(81)-Y(84)-II))) * Y(83)**(Y(84)+II)
     &       * (1.-Y(83))**(Y(81)-Y(84)-II)
 10   CONTINUE
      X(6) = SUM
      RETURN
      END
C
C  Function IFACT computes the factorial of an integer
C
      FUNCTION IFACT(III)
      IF (III .LT. 0) GO TO 20
      IF (III .EQ. 0) GO TO 40
      IFACT = 1
      DO 10 J = 1,III
      IFACT = IFACT*J
 10   CONTINUE
      RETURN
 20   WRITE (6,30)
 30   FORMAT (//,1X,'Factorial on a negative number
     & is not allowed.',//)
      RETURN
 40   IFACT = 1
      RETURN
      END
```

II. Assumption :

1. The minimum number of cranes is the number of cranes needed to accomplish SAL verification task in the ime allowed, given that no failures occur.
2. The number of cranes available is equal to or greater than the number of cranes needed for SAL verification.

Figure 4-6: x(6) Printout

5.0 OPTIMIZATION

5.1 Parameter Estimates

Parameter estimates are the values of y_k that are inputs to the criteria models, and therefore represent the link between a given candidate system and these criteria models, estimating the performance of that candidate system. The best available estimates of each y_k should be used. When these estimates become critical and accuracy of the y_k is questioned, the y_k should be verified from field data, testing, experimentation, or other reliable sources.

In order to expedite software implementation the University of Houston provided preliminary estimates of the 94 parameters for each of the 180 candidate systems. A sample candidate system is shown in Figure 5-1. The y_k are defined in Section 2.5, Figures 2-7 , through 2-12 and shown in a condensed form in Figure 5-2, the work sheet. Appendix A shows the total listing[5] of Table III. The worksheet of Figure 5-1 contains values for each of the 94 elements of candidate system #1. This candidate system represents fault detection and analysis in the OCC, with the option for detection being a go-no-go light display, fault analysis localized to LRU level, and the dispatch teams organized for special skills in each team resulting from the particular fault requirement.

The heading format in the data sheet is:

a [b, c, d, e]

CANDIDATE #1 [1, 1, 1, 1]

Scenario: Fault Detection and Analysis in OCC

Subsystems:

1. Go-no-go Light Display Detect
2. Analysis localized to LRU local
3. Dispatch organized for special skills in each team

PARAMETERS

	Value		Value		Value
1.	200	32.	0	63.	100
2.	2	33.	0	64.	2,000
3.	25	34.	0	65.	0.05
4.	25	35.	8,800	66.	3
5.	20	36.	1,232	67.	480
6.	20	37.	3,960	68.	20,000
7.	20	38.	20	69.	20,000
8.	0	39.	6	70.	25,000
9.	2	40.	20,000	71.	200,000
10.	6	41.	200,000	72.	1,000,000
11.	6	42.	1,000,000	73.	50,000,000
12.	2	43.	120,000	74.	50,000,000
13.	20	44.	120,000	75.	10,000,000
14.	20	45.	0	76.	100,000,000
15.	30	46.	120,000	77.	10,000,000
16.	200	47.	40,000	78.	1,000,000
17.	200	48.	40,000	79.	10,000
18.	7,000	49.	80,000	80.	10,000
19.	1.16	50.	1.16	81.	3
20.	0	51.	0	82.	100
21.	15	52.	180	83.	.999
22.	15	53.	4	84.	2
23.	30	54.	2,200	85.	500,000
24.	30	55.	2	86.	50
25.	123	56.	140,000	87.	100
26.	10^6	57.	0	88.	200
27.	60,000	58.	10,000	89.	2
28.	40,000	59.	3	90.	40,000
29.	.0004	60.	5	91.	60,000
30.	.0004	61.	2	92.	1
31.	.18	62.	0	93.	8
				94.	1

Figure 5-1: Candidate System #1

CANDIDATE # ____________________

Scenario: ____________________ Subsystems: 1. ____________________

2. ____________________

3. ____________________

P A R A M E T E R S

Name	Value	Name	Value	Name	Value
1. No. CMF's		32. No. Van Fail.		63. No. Per/OB	
2. No. OB's		33. No. MSS Fail.		64. No. Per/DAA	
3. No. Mult. T.		34. No. Heli. Fail.		65. Fract. N-L reg. Heli.	
4. No. Inspec. T.		35. Sp. Heli.		66. No. per CAMMS Miss. Loc.	
5. No. AVE moving T.		36. Sp. MSS		67. Cycle Time	
6. No. OSE R/R T.		37. Sp. Van		68. AVE. $/CMF per.	
7. No. C^3/sec. T.		38. No. ROSE repair T.		69. AVE. $/DB per.	
8. No. in Mult. T.		39. No. in AVE R/R T.		70. Ave. $/DAA per.	
9. No. in inspec. T.		40. $/VAN		71. $/STV	
10. No. in AVE R/R T.		41. $/MSS		72. $/CMF	
11. No. in OSE R/R T.		42. $/Heli.		73. $/OB	
12. No. in C^3/sec. T.		43. Per. $/OSE R/R T.		74. $/DAA	
13. No. AVE R/R T.		44. Per. $/AVE R/R T.		75. Eq. $/CMF	
14. No. FDD Heli.		45. Per. $/Mult. T.		76. Eq. $/OB	
15. No. FDD Vans		46. Per. $/moving T.		77. Eq. $/DAA	
16. No. MSS's		47. Per. $/inspec. T.		78. Inv. $/OMF	
17. No. clusters		48. Per. $/C^3/sec. T.		79. Inv. $/OB	
18. Dist. bet. P. 5.		49. Per. $/ROSE T.		80. Inv. $/DAA	
19. AVE empl. time		50. AVE remove time		81. No. cranes/cluster	
20. OSE empl. time		51. OSE remove time		82. No. crane T.	
21. AVE inspec. time		52. Delay (strat 2)		83. 7 day crane Reliab.	
22. OSE inspec. time		53. No. STV's		84. Min crane/cluster	
23. AVE repair time		54. Sp. STV		85. $/crane	
24. OSE repair time		55. No. DAA's		86. No. Heli. T.	
25. No. Per Miss. Loc.		56. Dist. DAA-CMF		87. No. Van T.	
26. Base oper. $		57. No. OSE Moving T.		88. No. FDD Sec. T.	
27. Heli. T. $		58. Dist. CMF-PS		89. No. in FDD sec T.	
28. Van. T. $		59. No. in Heli. T.		90. Per. $/FDD Sec T.	
29. No. Booster N-L		60. No. per./MSS		91. Per. $/crane T.	
30. No. RS N-L		61. No. in Van T.		92. SALT verif.	
31. No. MOSE/MGCS N-L		62. No. Per./CMF		93. Time/PS for PLM	
				94. Time E/E site	

Figure 5-2: Parameter Definitions

where:

a is the candidate system number

b is the detection method option

c is the fault localization option

d *is the team skill mix option*

e is the scenario option

The Figure 5-1 heading 1[1, 1, 1, 1] refers to the candidate system number 1, which is composed of the first of five options for the detection method, the first of four options for the level of localization of fault, the first of three options for the skill level mix of the team and the first of three scenarios covering location and contol of fault detection and analysis tasks.

5.2 Synthesis of Multiple Criterion Function

In order to achieve a performance index for each of the 180 candidate systems a rational procedure for combining the respective criterion models must be used. The format presented in Equation 15 represents an expedient approach toward evaluation of candidate system performance that includes each criterion at its respective relative importance.

$$CF_{\alpha} = \sum_{i=1}^{6} a_i X_i \qquad \text{(Eq. 15)}$$

Where:

CF_{α} is the figure of merit of the α candidate system

a_i is the relative importance of the i^{th} criterion

and:

$$X_i = \frac{x_i - x_{imin}}{x_{imax} - x_{imin}} \qquad \text{(Eq. 16)}$$

where:

x_i is the value resulting from the i^{th} criterion model of z_j and y_k

x_{imin} is the minimum value achieved from the set of candidate systems for the given criterion, x_i

x_{imax} is the maximum value achieved from the set of candidate systems for the given criterion, x_i

While this multiple criterion function form has been used before[5,6] it has several limitations[5]. The major one being the implicit assumption of independence among the set of criteria, $\{x_i\}$. Methods for estimating the effects of these criterion interactions have been developed at the University of Houston, but will not be used here in order to expedite the current results.

Major advantages of this CF are:

1. Unit measures of y_k are relegated to their respective value
2. Each criterion is limited in importance to the respective a_i defined for it
3. Explicit evaluation of criterion importance is estimated (and can be reexamined at will).

5.3 Ranking of Candidate Systems

Each of the 94 parameters were estimated for each of the 180 candidate systems. A computer program was then written that used a given set of estimates of the 94 parameters for a candidate system and each criterion computed for that candidate by computing the appropriate z_j and then the x_i. The minimum and maximum values of the respective x_i for the entire set of candidate were used to estimate X_i of Equation 16, and from this the CF_α was computed for each of the 180 candidate systems and then ranked. Figure 5-3 shows the top 50 candidate systems in descending order of values. From this ranking the subsequent analyses are made. Since improved estimates of the y_k are anticipated in a subsequent effort, the following is offered to illustrate how this analysis is approached.

From Figure 5-3, the observation is made that the top 5 candidate systems had an equal value of CF (0.394) and the next grouping of 5 candidates had the same value (0.368) within 6.5% of the top group well within the accuracy of these y_k estimates. The implication is that any of these top 10 candidates could be implemented with equal effectiveness of system performance. However, for demonstration purposes the y_k listing of the number one candidate is given in Figure 5-4.

The two top groups of candidate systems of Figure 5-3 had differences in the values of y_k as shown (remaining y_k were identical) in Figure 5-5.

Candidate System No. (α)		CF_{α}
1.	49.0	0.39408487
2.	37.0	0.39408487
3.	25.0	0.39408487
4.	13.0	0.39408487
5.	1.0	0.39408487
6.	50.0	0.36820496
7.	38.0	0.36820496
8.	26.0	0.36820496
9.	14.0	0.36820496
10.	2.0	0.36820496
11.	58.0	0.36409199
12.	55.0	0.36409199
13.	52.0	0.36409199
14.	46.0	0.36409199
15.	43.0	0.36409199
16.	40.0	0.36409199
17.	34.0	0.36409199
18.	31.0	0.36409199
19.	28.0	0.36409199
20.	22.0	0.36409199
21.	19.0	0.36409199
22.	16.0	0.36409199
23.	10.0	0.36409199
24.	7.0	0.36409199
25.	4.0	0.36409199
26.	109.0	0.36271399
27.	97.0	0.36271399
28.	85.0	0.36271399
29.	73.0	0.36271399
30.	61.0	0.36271399
31.	51.0	0.35534907
32.	39.0	0.35534907
33.	27.0	0.35534907
34.	15.0	0.35534907
35.	3.0	0.35534907
36.	110.0	0.33888446
37.	98.0	0.33888446
38.	86.0	0.33888446
39.	74.0	0.33888446
40.	62.0	0.33888446
41.	118.0	0.33385148
42.	115.0	0.33385148
43.	112.0	0.33385148
44.	106.0	0.33385148
45.	103.0	0.33385148
46.	100.0	0.33385148
47.	94.0	0.33385148
48.	91.0	0.33385148
49.	88.0	0.33385148
50.	82.0	0.33385148

Figure 5-3: The Top Ranked 50 Candidate Systems

CANDIDATE #49 [5, 1, 1, I]

Scenario: Fault Detection and Analysis in OCC

Subsystems:

1. Simultaneous display of some combination of all 4 alternatives.
2. Localized to Subsystem level
3. Organize for specialized skill teams

P A R A M E T E R S		
Value	Value	Value
1. 200	32. 0	63. 100
2. 2	33. 0	64. 2,000
3. 25	34. 0	65. .05
4. 20	35. 8,800	66. 3
5. 20	36. 1,232	67. 480
5. 20	37. 3,960	68. 20,000
6. 20	38. 20	69. 20,000
7. 20	39. 6	70. 25,000
8. 0	40. 20,000	71. 200,000
9. 2	41. 200,000	72, 1,000,000
10. 6	42. 1,000,000	73. 50,000,000
11. 6	43. 120,000	74. 50,000,000
12. 2	44. 120,000	75. 10,000,000
13. 20	45. 0	76. 100,000,000
14. 20	46. 120,000	77. 100,000,000
15. 30	47. 40,000	78. 1,000,000
16. 200	48. 40,000	79. 10,000
17. 200	49. 80,000	80. 10,000
18. 7,000	50. 1.16	81. 3
19. 1.16	51. 0	82. 100
20. 0	52. 180	83. .999
21. 15	53. 4	84. 2
22. 15	54. 2,200	85. 500,000
23. 30	55. 2	86. 50
24. 30	56. 140,000	87. 100
25. 0	57. 0	88. 200
26. 1,000,000	58. 10,000	89. 2
27. 60,000	59. 3	90. 40,000
28. 40,000	60. 5	91. 60,000
29. .0004	61. 2	92. 1
30. .0004	62. 0	93. 8
31. .18		94. 1

Figure 5-4: Parameter Listing for Optimal Candidate

y_k	Description	Top 5 Candidate Systems	Next 5 Candidate Systems
y_8	NO. IN MULTIPLE SKILL TEAM	0	4
y_{11}	NO. IN OSE R/R TEAM	6	4
y_{23}	AVE REPAIR TIME	30	40
y_{24}	OSE REPAIR TIME	30	40
y_{39}	NO. IN AVE R/R TEAM	6	4
y_{43}	PERSONNEL COST/OSE R/R TEAM	120,000	80,000
y_{44}	PERSONNEL COST/AVE R/R TEAM	120,000	80,000
y_{45}	PERSONNEL COST/ MULTIPLE SKILL TEAM	0	80,000

Figure 5-5: Comparison of Differences in y_k For the Top Ranked Sets of Candidate Systems

The major implication observed from this figure is that the savings in repair time merits the increase in personnel costs indicated for the top 5 candidate systems(with all the attendant values limit into the CF). Additional analysis of the differences in the candidate systems would be merited with improved accuracy of y_k input.

This discussion illustrates the procedure for analyzing the choice of candidate system from the printout. It is apparent that interpretation of the printout is strongly dependent on the accuracy of the y_k and of the models.

5.4 Design Space Search

The design space is defined as the hyperspace resulting from the range of each parameter, y_k, and that of the criterion function, CF_α . Hence all feasible solutions exist within this space.

A candidate system can then be defined as the vector of parameters and the resultant value of CF_α. Further, a candidate system is feasible only when every value of y_k in its vector exists in the design space. Conversely, a candidate system is not feasible when one or more of the y_k in its vector lies outside the design space.

In section 5.3 the discussion dealt with the ranking of the available candidate systems in order of their desirability as determined by CF. The purpose of the Design Space Search is to obtain the maximum value of CF from the design space along with the attendant set, y_k which yields this the theoretic maximum CF. The existence of this set does not necessarily imply the existence of a real candidate system, but always indicates a maximum "performance" which is theoretically possible.

It is readily shown that Equation 15, has the following limits:

$$0 \leq CF \geq 1.0 \qquad \text{(Eq. 17)}$$

However, for complex systems the CF_α value of 1.0 seldom exists. Hence the search for the maximum CF in the design space must be accomplished.

The difficulties encountered in this search resulted mostly

from:

1. The CF is highly non-linear
2. The large number of parameters, y_k

Two fundamental approaches were used. The first was based on a search algorithm, and the second on random optimization.

In the random optimization values for the 94 parameters are selected randomly from the feasible range, and their CF computed. In a sense random candidate systems are being generated and ranked. However, these candidate systems may not be real since they are created from a random combination of parameters without relating to any specific equipment configuration or operational scenario.

The second approach was to use two analytical methods, the generalized reduced gradient (GRG) and the sequential unconstrained maximization(SUMT). GRG uses the partial derivatives of the CF with respect to each of the 94 parameters to determine the "best" direction to move in the design space so that the GRG technique follows a steepest ascent algorithm. However, GRG requires large amounts of computer time without assurance of achieving the "global maximum" within the design space, particularly in view of the large number of y_k. The technique works well when CF is continuous and $k \leq 20$.

SUMT, the second approach uses a penalty function in the selection of a new candidate system. It does not require algorithms and it can incorporate constraints. SUMT was proposed as an extension[9] of the created response surface technique and was subsequently developed into a computational agorithm[10, 11]. The programming problem under

consideration is that of determining a 94 dimensional vector, V, that maximizes the CF(V) subject to the range constraints g_i and equality constraints, h_j such that

$$g_i(0),\ i = 1,\ \ldots,\ m$$

$$h_j = (0),\ j = 1,\ \ldots,\ p$$

SUMT is based on the minimization of the penalty function P(V,r), where:

$$P(V,r) = CF(V) + r_k \sum_{i=1}^{m} \frac{1}{g_i(v)} + r^{\frac{1}{2}} \sum_{j=1}^{p} h^2(v)$$

The essential requirement in SUMT as in most non-linear minimization algorithms is that the CF(V) must be convex in order to achieve a global minimum. To mitigate the problem of lack of convexity a modified Newton-Raphson search has been added to SUMT.

The best value of CF was obtained from the randomized method by simply choosing random values of y_k within the defined range for each y_k. After many hours of micro-computer operation, $CF_{max}=0.58506$ was obtained and this is shown in Figure 5-6. This figure shows the comparison of Candidate System #49, the top ranked of the 180 candidate systems examined, with the candidate resulting from the design space search (CF = .58506). Study of this figure shows that all of the y_k with the exception of those listed below have not changed. The changes are shown in Figure 5-7.

It is of interest to note that, for the inputs chosen, overall

Scenario: __________ Subsystems: 1. __________

2. __________

3. __________

PARAMETERS

y_k	CF_{49}	Theoretic Optimal	y_k	CF_{49}	Theoretic Optimal	y_k	CF_{49}	Theoretic Optimal
1.	200	200	32.	0	0	63.	100	100
2.	2	1	33.	0	0	64.	2000	2000
3.	25	27	34.	0	0	65.	0.05	.05
4.	20	21	35.	8800	8800	66.	3	5
5.	20	20	36.	1232	1232	67.	480	480
6.	20	20	37.	3960	3960	68.	20,000	20,000
7.	20	21	38.	20	20	69.	20,000	20,000
8.	0	0	39.	6	6	70.	25,000	25,000
9.	2	2	40.	20,000	20,000	71.	200,000	200,000
10.	6	6	41.	200,000	200,000	72.	1,000,000	1,000,000
11.	6	6	42.	1,000,000	1,000,000	73.	50,000,000	50×10^6
12.	2	2	43.	120,000	120,000	74.	50,000,000	50×10^6
13.	20	20	44.	120,000	120,000	75.	10,000,000	10^7
14.	20	15	45.	0	0	76.	100,000,000	10^6
15.	30	30	46.	120,000	120,000	77.	100,000,000	10^8
16.	200	200	47.	40,000	40,000	78.	1,000,000	10^6
17.	200	200	48.	40,000	40,000	79.	10,000	10^4
18.	7000	7000	49.	80,000	80,000	80.	10,000	10^4
19.	1.16	1.16	50.	1.16	1.16	81.	3	4
20.	0	0	51.	0	0	82.	100	100
21.	15	15	52.	180	180	83.	0.999	0.999
22.	15	15	53.	4	4	84.	2	2
23.	30	35	54.	2200	2200	85.	500,000	5×10^5
24.	30	20	55.	2	2	86.	50	50
25.	0	0	56.	140,000	140,000	87.	100	100
26.	1,000,000	10^6	57.	0	0	88.	200	200
27.	60,000	60,000	58.	10,000	10,000	89.	2	2
28.	40,000	40,000	59.	3	3	90.	40,000	40,000
29.	0.0004	0.0004	60.	5	5	91.	60,000	60,000
30.	0.0004	0.0004	61.	2	2	92.	1	1
31.	0.18	.18	62.	0	0	93.	8	8
						94.	1	1

Figure 5-6 Comparison of y_k Values for Best Candidate System (#49) With Theoretic Optimal Candidate System

y_k	Name	CS#49	CS*
2	Number of OB	2	1
3	Number of Multiple Skill Teams	25	27
4	Number of Inspection Teams	20	21
7	Number of C^3 Security Repair Teams	20	21
14	Number of Helicopters assigned to FDD	20	15
23	AVE Repair Time	30	35
66	Number of CAMMS Personnel who need to know Missile Location	3	5
81	Number of cranes per cluster	3	4

Figure 5-7: Comparison of y_k that changed from CS#49 to Theoretic Optimal Candidate System, CS*

performance of the FDD is improved (as defined by CF_α) when the number of multiple skill teams, number of inspection teams, number of C^3 Security Repair Teams, the AVE repair time, number of CAMMS personnel who need to know the missile location and the number of cranes/cluster are each increased as shown while the remaining y_k are each decreased as shown in Figure 5-7.

Additional effort in the improvement of y_k input accuracy and CF_α output analysis will be accomplished in subsequent effort.

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APPLICATION OF A DESIGN MORPHOLOGY TO THE MX/OCC DEFINITION OF --ETC(U)
SEP 80 B OSTROFSKY, C E DONAGHEY F49620-77-C-0116
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6.0 INITIAL STUDY OF MAINTENANCE CONTROL INFORMATION FLOW

The information flow for maintenance activities originating from protective structure (PS) to OCC, among activity centers at OCC and particularly from Computer Aided Maintenance Management Systems (CAMMS) are covered in this section.

6.1 Information Flow Between PS and OCC

The information flow between PS and OCC is identified in Figure 6.1. Fault detection to the Line Replaceable Unit (LRU), by Remote Fault Detection/Isolation System, is broken down to the major equipment/facility, i.e. Transporter Erector Launcher (TEL), Resident Support Equipment (ROSE), Resident Operational Support Equipment Enclosure (ROSEE) and antenna systems. Further, an attempt is made to identify the modules within the equipment/facility. TEL/Mobile Surveillance Shield (MSS) is covertly emplaced in one of the 23 Horizontal Shelter Sites, but a fault indication from it uniquely identifies the location of the missile, even though the signatures originating from protective structures with and without TEL/MSS are the same. The information flow from maintenance activities from time compliance technical order (T/O) is also indicated in the Figure 6.1. OCC obtains the information using the MX Communications network. The Figure 6.1, also, identifies the activities center at OCC/Alternate OCC(AOCC). It assumed that the activities and capabilities of OCC and AOCC are essentially the same, hence reference to OCC means OCC/AOCC in subsequent sections.

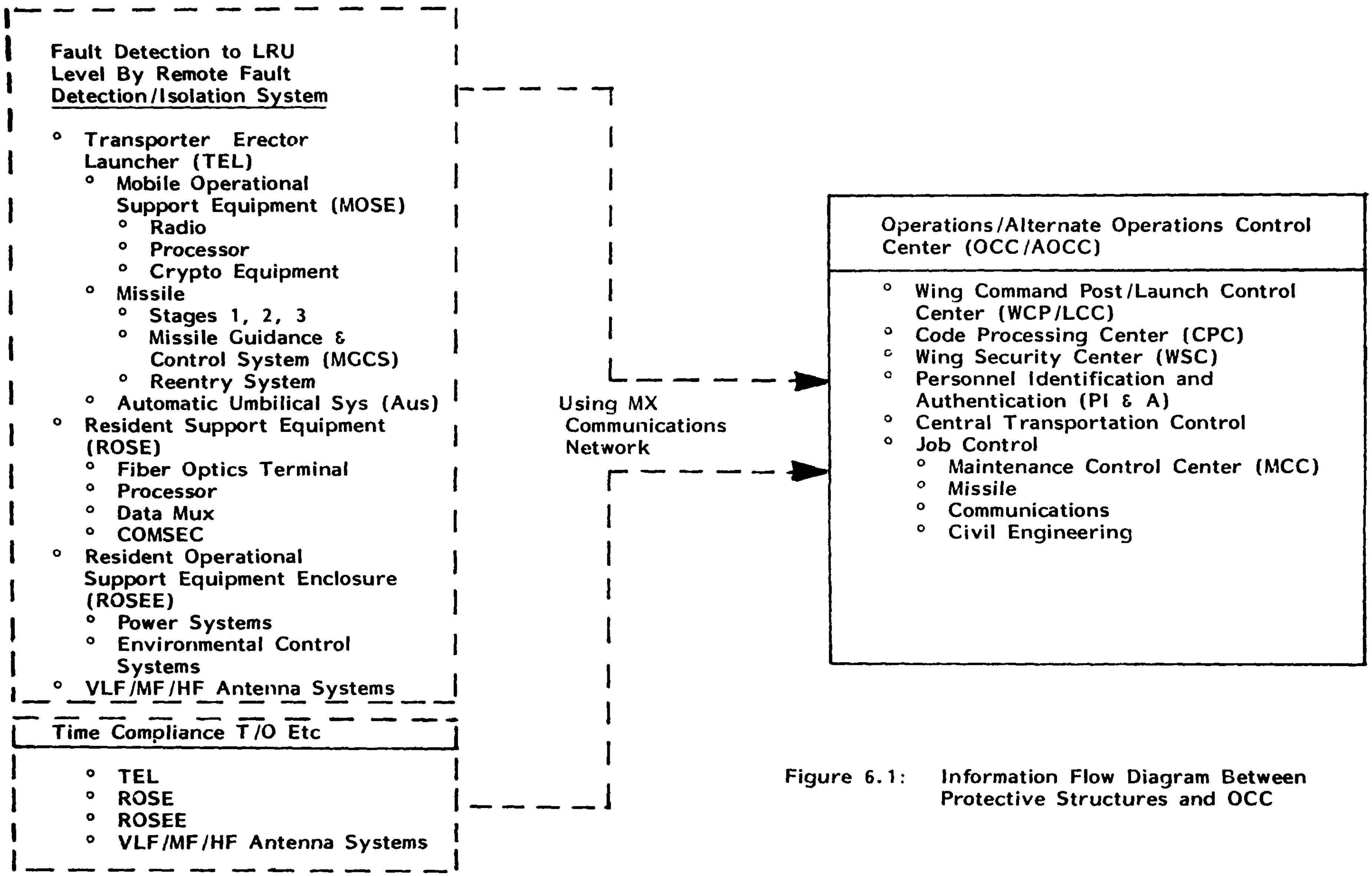

Figure 6.1: Information Flow Diagram Between Protective Structures and OCC

6.2 Interaction of Activity Centers at OCC

The operational functions and the interactions of various activity centers at OCC are identified in Figure 6.2. Note that CAMMS provides a user-oriented, distributed processing, data based system for supporting near real time management of MX maintenance. Thus, the Figure 6.2 identifies the routes for dissemination of data, originating from fault detection at a PS.

6.3 CAMMS Subsystems

CAMMS is supported by four subsystems. Figure 6.3 identifies the major functions of the subsystems. Figures 6.4 thru 6.7 indicate the processes involved in these subsystems and also provides the outputs generated from the analysis performed in these subsystems.

6.4 Maintenance Levels for LRU Failures

An attempt is made to identify the maintenance levels for LRU failures and a list of possible LRU failures from equipment at PS is indicated in Table 6.8. Further, it provides the basic philosophy for each maintenance level, i.e. organization, intermediate and depot. The type of equipment used at each maintenance level facility is also indicated. Identification of current baseline for Organizational Level (OL), Intermediate Level (IL) and Depot Level (DL) maintenance activities is yet to be determined and this Table 6-8 will identify additional LRU and maintenance activities.

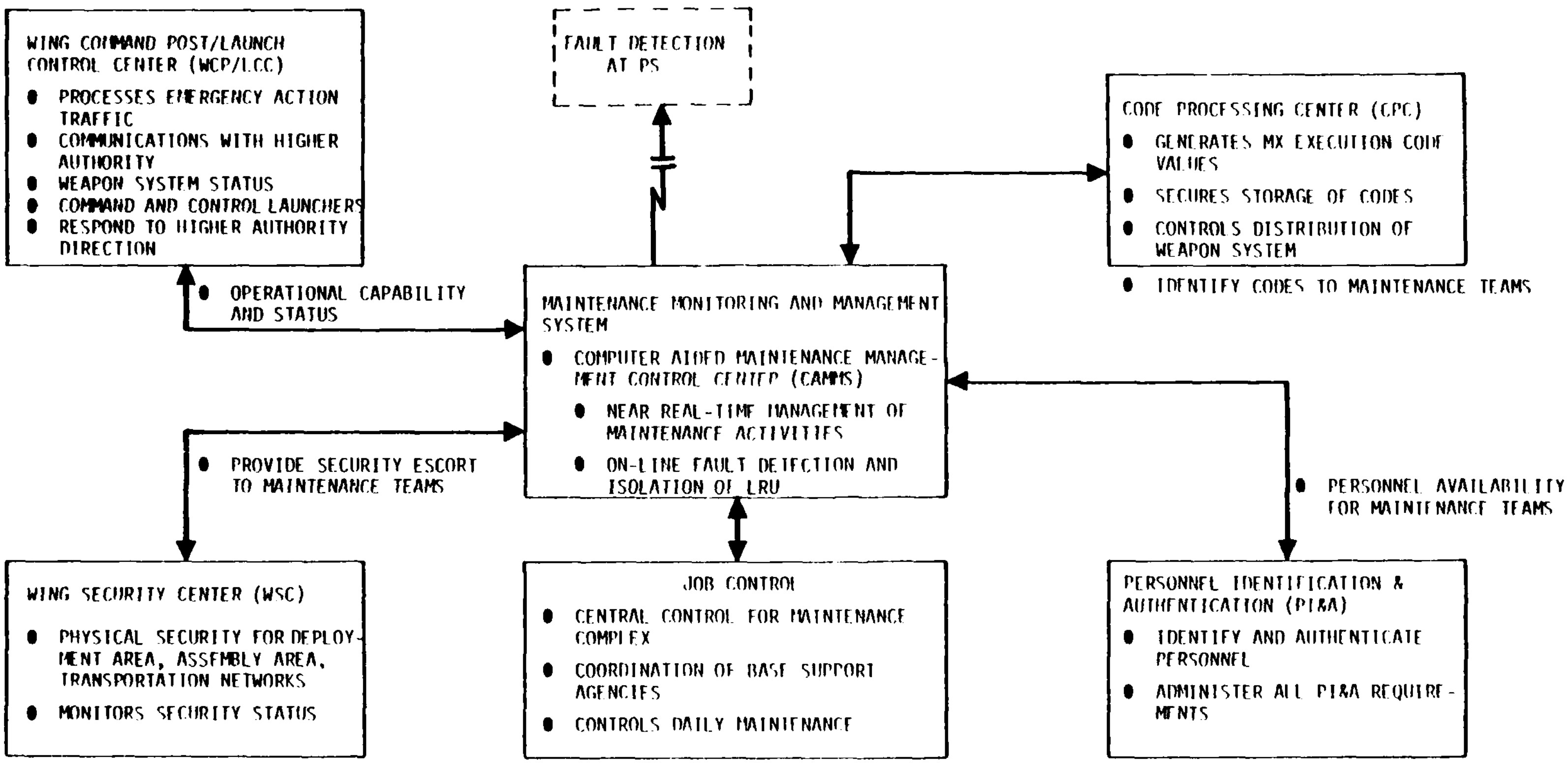

FIGURE 6-2 INTERACTION ACTIVITIES BETWEEN ACTIVITY CENTERS AT OCC

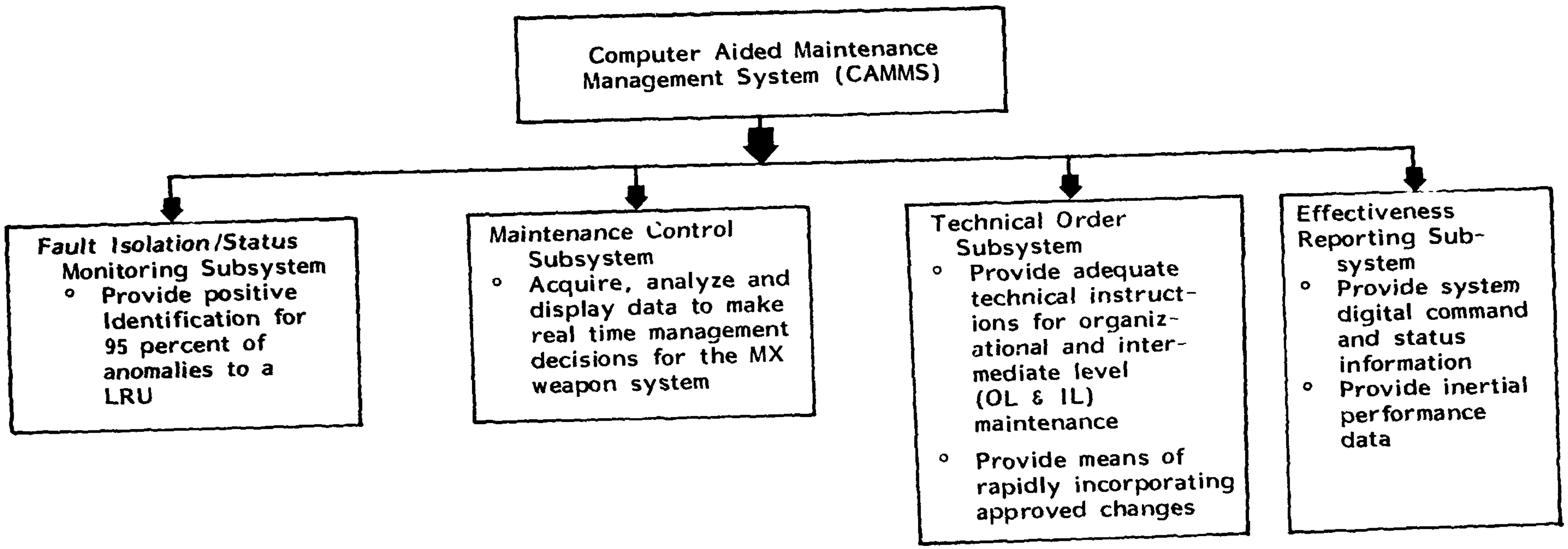

Figure 6.3 Subsystems of Computer Aided Maintenance Management System

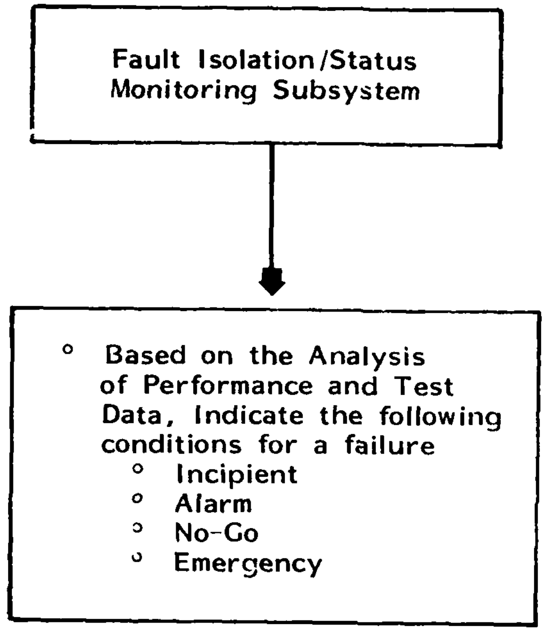

Figure 6.4 Fault Isolation/Status Monitoring Subsystem Activities

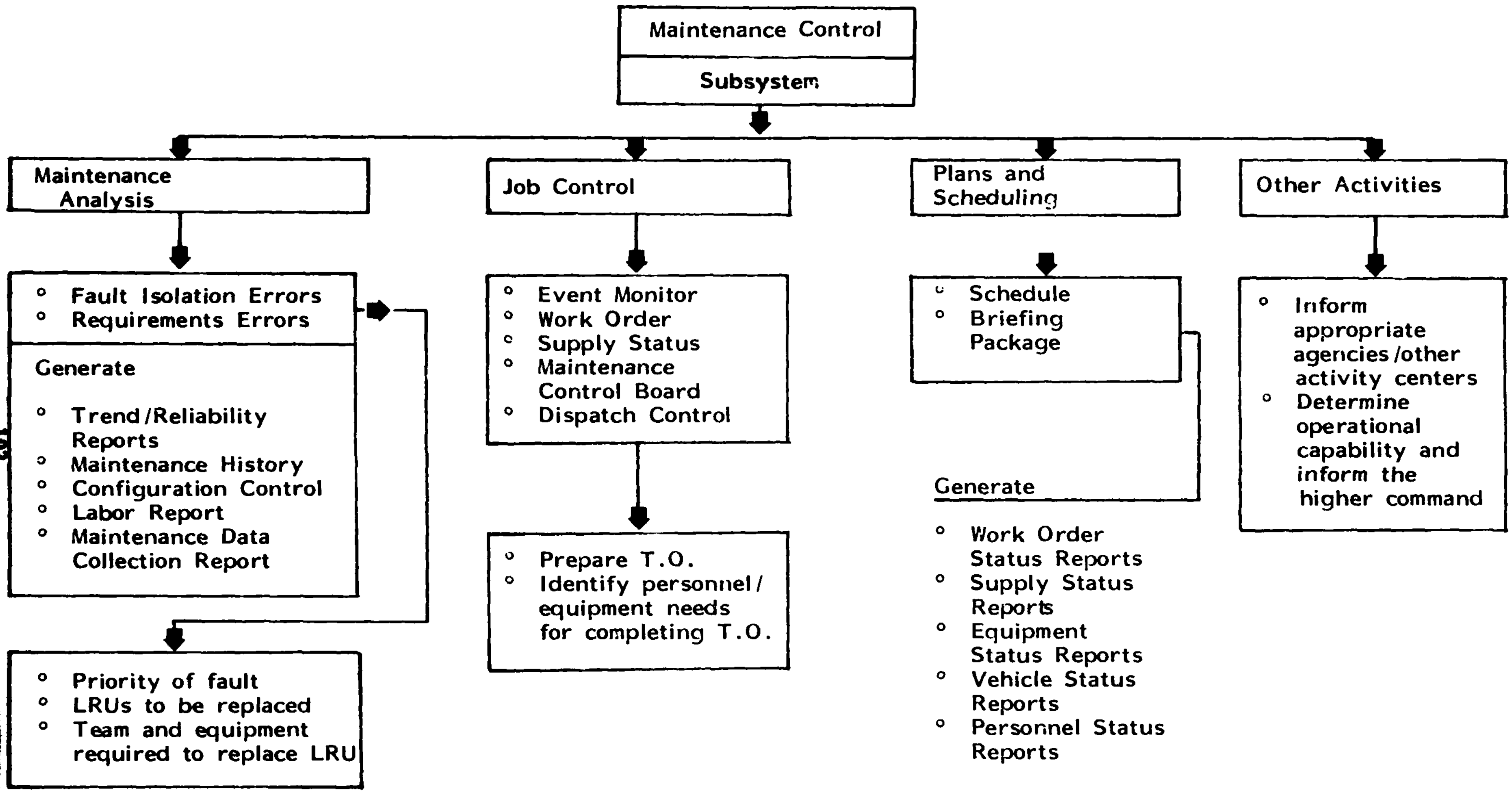

Figure 6.5 Maintenance Control Subsystem Activities

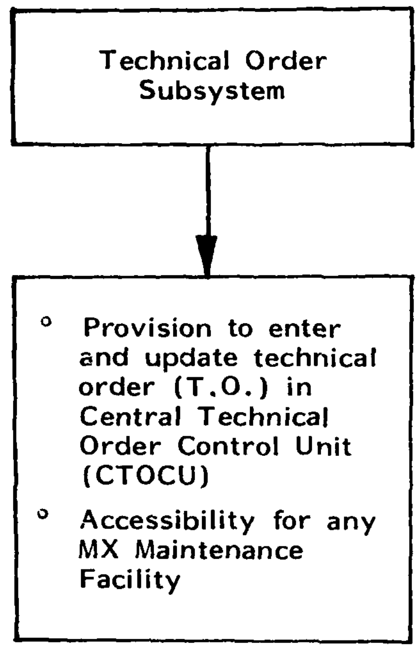

Figure 6.6 T. O. Subsystem Activities

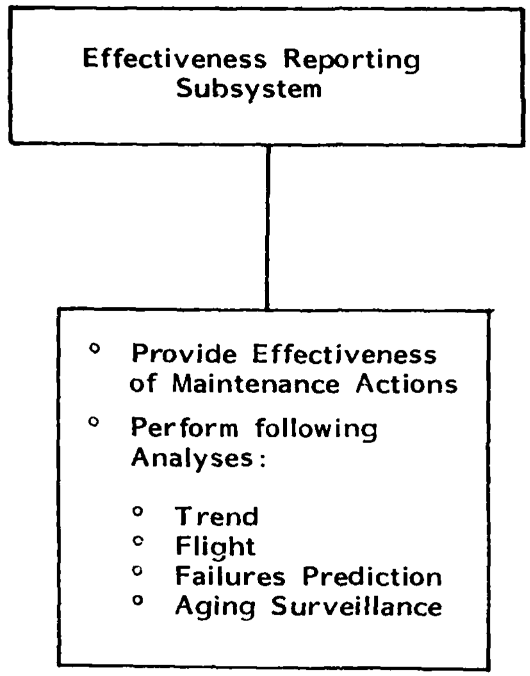

Figure 6.7 Effectiveness Reporting Subsystem

Identifiable LRU Failures	OL Philosophy	IL	DL
° Transporter Erector Launcher (TEL) ° Mobile Operational Support Equipment (MOSE) ° Radio ° Processor ° Crypto Equipment ° Missile/ ° Stages 1, 2, 3 ° Missile Guidances Control System (MGCS) ° Reentry System ° Automatic Umbilical System ° Resident Support Equipment (ROSE) ° Fiber Optics Terminal ° Data Mux ° COMSEC ° Resident Operational Support Equipment Enclosure (ROSEE) ° Power Systems ° Environmental Control Systems ° VLF/MF/HF Antenna Systems	° Self-test and Diagnostic Maintenance ° Remove and Replace (RIR) of Failed Unit ° Equipment ° 3 Portable Specialized Test Sets for Testing FO Cables, electronic surge and the buried antennas ° Responsible facility ° DASC/CMF	° Uses ATE for repair of fault drawer, ATR boxes and major assemblies ° Isolation of PC cord or module ° Equipment ° ATE ° Commercially available instrumentation ° Responsible facility ° Designated Assembly Area (DAA)	° Uses integrated IL/DL ATE for fault isolation to the piece part level of removed LRUs. ° Equipment ° ATE ° Computer aided design simulation and automatic test generating ° Responsible facility ° DAA

Table 6.8 Identification of Maintenance Levels for LRU Failures

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

7.1.1 Application of this design morphology appears to be effective for the development of the optimal maintenance control activities. Since the FY 78 research demonstrated effective application of this morphology to aerospace equipment, substantive verification is obtained for the use of this design morphology to both structured and unstructured aerospace systems.

7.1.2 The difficulties of problem definition are greatly clarified for the large scale system through the use of this morphology. The accomplishment of a requirements study and an input-output analysis tended to clarify and to bound the problem definition, and provided a more pointed direction to proceed.

7.1.3 The synthesis of the three scenarios, the resulting 180 candidate systems, the definition of criteria and their respective relative weights, the identification of submodels and parameters, the modeling, and finally, the computer software development were all accomplished in a straight-forward manner. Hence verification of the usefulness of the morphology has been demonstrated.

7.1.4 The design morphology provided a useful vehicle for clearly defining the functions or tasks that are required to meet the needs of the fault detection and dispatch activity. Hence the role of human factors and logistics in the FDD becomes clear when scenarios are developed. In particular, the subsequent definition of implementation

details depend almost entirely on the adequacy of the consideration given these two areas.

7.1.5 The multiple criterion function as developed in this research assures the proper mix of man-machine activity since "soft" data is included explicitly in the optimization. Hence the highest ranked system identifies the "best" candidate system, and this greatly clarifies the man-machine interface.

7.1.6 This structured design process speeds designer awareness in the technological areas. By adhering to this design process the team was able to quickly define relevant problem areas, and this was able to become conversant in the MX situation more rapidly than is normal for such high technology systems.

7.1.7 The FDD optimization process is now completely structured for the operational conditions defined during this research. The multiple criterion function, CF_{α} is developed, programmed, and was exercised with estimated parameters, y_k. A method to estimate possible performance growth of FDD was developed from the design space structured by the y_k ranges. This identifies the parameters that should change to improve FDD efficiency to the maximum practical level.

7.1.8 A major result of this optimization is the recognition that FDD activity should be physically close to OCC in order to maximize the effectiveness of the maintenance control activity.

7.1.9 The simulation of MX cluster maintenance has been demonstrated, and development of a multiple cluster program is under way.

This simulation appears to be effective in comparing various maintenance policies and estimating MX cluster availability.

7.1.10 The multiple criterion function, once structured in the manner demonstrated herein, provides a method for evaluating the effects of reliability, maintainability, quality assurance, and system effectiveness. It further provides a means for assuring optimal skill level mixes for the maintenance teams by evaluating the resulting values of y_k in CF_α when the relevant criteria are included.

7.1.11 The OCC information flow diagrams of section 6.0 present the top level maintenance requirements in the OCC and can be used to verify the completeness of proposed contractors systems.

7.2 Recommendations

7.2.1 In order to develop the multiple criterion function UH assumed parameter values for the required y_k from their existing, available information. Follow-on effort should improve the y_k accuracy, to achieve the attendant improvement in discrimination among the candidate system and a possible change in the most desirable configuration.

7.2.2 The OCC information flow study should proceed to develop greather detail for integration of CAMMS into the MX system.

7.2.3 The maintenance simulation should be completed with the integration of a multiple cluster model which could then be available for estimating new concepts and changes in MX maintenance planning and control.

7.2.4 Analytical methods for improving the multiple criterion function accuracy should be developed.

7.2.5 With the resulting improved CF_{α} accuracy from improvement of input parameter accuracy, other avenues of development to find a global maximum in the design space should be developed for this CF_{α}.

7.2.6 A software system should be developed to allow MX management with minimal computer background to obtain answers to "what-if" questions. This system should be self-contained, in the sense of having its own vocabulary in plain English available to the user as well as a well documented "heep" library on-line.

7.2.7 Study of the interactions of reliability, maintainability, quality assurance, and system readiness should be made. The output of this study should show how the relevant variables affect the criteria, x_i, in the CF_{α} and hence maximize system effectiveness for the resources used.

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APPENDIX A – LISTING OF PARAMETERS ("TABLE III")

		x(1)					x(2)				x(3)					x(4)				x(5)			x(6)
	Z(j)	1	3	4	8	D	3	4	8	D	2	5	6	7	D	3	4	8	D	4	8	D	D
																				X			
Z(1)	Number of personnel for FDD	X																					
Z(2)	FDD equipment and facilities cost ($)										X												
Z(3)	Task time (minutes)		X				X									X				X			
Z(4)	Dispatch time (minutes)			X				X									X			X			
Z(5)	FDD personnel cost ($)											X											
Z(6)	FDD vehicle cost ($)												X										
Z(7)	FDD operating and spare cost ($)													X									
Z(8)	Number of actions per month				X				X									X			X		

		X(1)					X(2)				X(3)					X(4)				X(5)			X(6)
																				X			
	Z(j)	1	3	4	8	D	3	4	8	D	2	5	6	7	D	3	4	8	D	4	8	D	D
Y(1)	Number of CMF's	X									X	X		X									
		X									X	X		X									
Y(2)	Number of OB's	X									X	X		X									
		X									X	X		X									
Y(3)	Number of multiple	X										X											
	skill teams	X										X											
Y(4)	Number of inspection	X										X											
	teams	X										X											
Y(5)	Number of AVE moving	X																					
	teams	X																					
Y(6)	Number of OSE R/R teams	X										X											
		X										X											
Y(7)	Number of C**3/security	X										X											
	repair teams	X										X											
Y(8)	Number in multiple skill	X																					
	team	X																					
Y(9)	Number in inspection team	X																					
		X																					
Y(10)	Number in AVE moving team	X																					
		X																					

		X(1)					X(2)				X(3)					X(4)				X(5)			X(6)
																				X			
	Z(j)	1	3	4	8	D	3	4	8	D	2	5	6	7	D	3	4	8	D	4	8	D	D
Y(11)	Number in OSE R/R team	X																					
		X																					
Y(12)	Number in C**3/security repair team	X																					
		X																					
Y(13)	Number of AVE R/R teams	X										X											
		X										X											
Y(14)	Number of helicopters assigned to FDD	X											X									X	
		X											X									X	
Y(15)	Number of vans assigned to FDD	X											X									X	
		X											X									X	
Y(16)	Number of MSS's	X											X									X	
		X											X									X	
Y(17)	Number of clusters												X									X	
													X									X	
Y(18)	Distance between PS (feet)			X				X									X		X	X		X	
				X				X									X		X	X		X	
Y(19)	AVE emplacement time (minute)		X				X									X				X			
			X				X									X				X			
Y(20)	OSE emplacement time (minute)		X				X									X				X			
			X				X									X				X			

```
-----------------------------------------------------------------------------------------------
|      |                              |   X(1)     |  X(2)    |   X(3)     |  X(4)    | X(5)   |X(6)|
-----------------------------------------------------------------------------------------------
|      |                              | : : : : : | : : : : | : : : : : | : : : : | : : : | : |
|      |                              | : : : : : | : : : : | : : : : : | : : : : | : : : | : |
|      |                              | : : : : : | : : : : | : : : : : | : : : : | : : : | : |
|      |                              | : : : : : | : : : : | : : : : : | : : : : |X: : : | : |
|      |                          Z(j)|1:3:4:8:D: |3:4:8:D: |2:5:6:7:D: |3:4:8:D: |4:8:D: |D: |
-----------------------------------------------------------------------------------------------
|Y(21)|AVE inspection time            | :X: : : : |X: : : : | : : : : : |X: : : : |X: : : | : |
|      |(minute)                      | :X: : : : |X: : : : | : : : : : |X: : : : |X: : : | : |
-----------------------------------------------------------------------------------------------
|Y(22)|OSE inspection time            | :X: : : : |X: : : : | : : : : : |X: : : : |X: : : | : |
|      |(minute)                      | :X: : : : |X: : : : | : : : : : |X: : : : |X: : : | : |
-----------------------------------------------------------------------------------------------
|Y(23)|AVE repair time                | :X: : : : |X: : : : | : : : : : |X: : : : |X: : : | : |
|      |(minute)                      | :X: : : : |X: : : : | : : : : : |X: : : : |X: : : | : |
-----------------------------------------------------------------------------------------------
|Y(24)|OSE repair time                | :X: : : : |X: : : : | : : : : : |X: : : : |X: : : | : |
|      |(minute)                      | :X: : : : |X: : : : | : : : : : |X: : : : |X: : : | : |
-----------------------------------------------------------------------------------------------
|Y(25)|Number of maint. personnel     | : : : :X: | : : : : | : : : : : | : : : : | : : : | : |
|      |knowing any missile loc.      | : : : :X: | : : : : | : : : : : | : : : : | : : : | : |
-----------------------------------------------------------------------------------------------
|Y(26)|Base operating support         | : : : : : | : : : : | :X: : : : | : : : : | : : : | : |
|      |cost ($)                      | : : : : : | : : : : | :X: : : : | : : : : | : : : | : |
-----------------------------------------------------------------------------------------------
|Y(27)|Helicopter team personnel      | : : : : : | : : : : | :X: : : : | : : : : | : : : | : |
|      |cost ($)                      | : : : : : | : : : : | :X: : : : | : : : : | : : : | : |
-----------------------------------------------------------------------------------------------
|Y(28)|Van team personnel cost        | : : : : : | : : : : | :X: : : : | : : : : | : : : | : |
|      |($)                           | : : : : : | : : : : | :X: : : : | : : : : | : : : | : |
-----------------------------------------------------------------------------------------------
|Y(29)|Num. of booster no launch      | :X:X:X: : |X:X:X: : | : : : : : |X:X:X:X: |X:X:X: | : |
|      |failures/mon. per missile     | :X:X:X: : |X:X:X: : | : : : : : |X:X:X:X: |X:X:X: | : |
-----------------------------------------------------------------------------------------------
|Y(30)|Number of RS no launch         | :X:X:X: : |X:X:X: : | : : : : : |X:X:X:X: |X:X:X: | : |
|      |failures/mon. per missile     | :X:X:X: : |X:X:X: : | : : : : : |X:X:X:X: |X:X:X: | : |
-----------------------------------------------------------------------------------------------
```

		X(1)					X(2)				X(3)					X(4)				X(5)			X(6)
																				X			
	Z(j)	1	3	4	8	D	3	4	8	D	2	5	6	7	D	3	4	8	D	4	8	D	D
Y(31)	Num of MOSE/MGCS no launch failures/mon. per missile		X	X	X		X	X	X							X	X	X		X	X		
Y(32)	Number of van failures/ month																						
Y(33)	Number of MSS failures/ month																						
Y(34)	Number of helicopter failures/month																						
Y(35)	Speed of helicopter (feet/minute)		X	X			X	X								X	X			X		X	
Y(36)	Speed of MSS (feet/minute)			X				X									X		X	X		X	
Y(37)	Speed of van (feet/minute)			X				X									X		X	X		X	
Y(38)	Number of ROSE repair teams											X											
Y(39)	Number in AVE R/R team	X																					
Y(40)	Cost/van ($)												X										

		X(1)					X(2)				X(3)					X(4)				X(5)			X(6)
	Z(j)	1	3	4	8	D	3	4	8	D	2	5	6	7	D	3	4	8	D	4	8	D	D
																				X			
Y(41)	Cost/MSS ($)												X										
Y(42)	Cost/helicopter ($)												X										
Y(43)	Personnel cost/OSE R/R team											X											
Y(44)	Personnel cost/AVE R/R team											X											
Y(45)	Personnel cost/multiple skill team											X											
Y(46)	Personnel cost per AVE/OSE moving team											X											
Y(47)	Personnel cost/inspection team											X											
Y(48)	Personnel cost/C**3 - security repair team											X											
Y(49)	Personnel cost/ROSE repair team											X											
Y(50)	AVE removal time (minute)		X				X									X				X			

```
---------------------------------------------------------------------------------------------
|      |                          |   X(1)     |  X(2)    |   X(3)     |  X(4)    | X(5)   |X(6)|
---------------------------------------------------------------------------------------------
|      |                          | : : : : :  | : : : :  | : : : : :  | : : : :  | : : :  | :  |
|      |                          | : : : : :  | : : : :  | : : : : :  | : : : :  | : : :  | :  |
|      |                          | : : : : :  | : : : :  | : : : : :  | : : : :  | : : :  | :  |
|      |                          | : : : : :  | : : : :  | : : : : :  | : : : :  |X: : :  | :  |
|      |                     Z(j) |1:3:4:8:D:  |3:4:8:D:  |2:5:6:7:D:  |3:4:8:D:  |4:8:D:  |D:  |
---------------------------------------------------------------------------------------------
|Y(51)|OSE removal time           | :X: : : :  |X: : : :  | : : : : :  |X: : : :  |X: : :  | :  |
|     |(minute)                   | :X: : : :  |X: : : :  | : : : : :  |X: : : :  |X: : :  | :  |
---------------------------------------------------------------------------------------------
|Y(52)|Delay (minute)             | : : : : :  | :X: : :  | : : : : :  | :X: :X:  |X: :X:  | :  |
|     |                           | : : : : :  | :X: : :  | : : : : :  | :X: :X:  |X: :X:  | :  |
---------------------------------------------------------------------------------------------
|Y(53)|Number of STV's            | : : : : :  | : : : :  | : :X: : :  | : : : :  | : :X:  | :  |
|     |                           | : : : : :  | : : : :  | : :X: : :  | : : : :  | : :X:  | :  |
---------------------------------------------------------------------------------------------
|Y(54)|Speed of STV               | : : : : :  | :X: : :  | : : : : :  | :X: : :  |X: :X:  | :  |
|     |                           | : : : : :  | :X: : :  | : : : : :  | :X: : :  |X: :X:  | :  |
---------------------------------------------------------------------------------------------
|Y(55)|Number of DAA's            |X: : : : :  | : : : :  |X:X: :X: :  | : : : :  | : : :  | :  |
|     |                           |X: : : : :  | : : : :  |X:X: :X: :  | : : : :  | : : :  | :  |
---------------------------------------------------------------------------------------------
|Y(56)|Distance between DAA       | : : : : :  |X:X: : :  | : : : : :  |X:X: :X:  |X: :X:  | :  |
|     |and CMF                    | : : : : :  |X:X: : :  | : : : : :  |X:X: :X:  |X: :X:  | :  |
---------------------------------------------------------------------------------------------
|Y(57)|Number of OSE moving teams | : : : : :  | : : : :  | :X: : : :  | : : : :  | : : :  | :  |
|     |                           | : : : : :  | : : : :  | :X: : : :  | : : : :  | : : :  | :  |
---------------------------------------------------------------------------------------------
|Y(58)|Distance between CMF       | : :X: : :  | :X: : :  | : : : : :  | :X: : :  |X: :X:  | :  |
|     |and PS                     | : :X: : :  | :X: : :  | : : : : :  | :X: : :  |X: :X:  | :  |
---------------------------------------------------------------------------------------------
|Y(59)|Number in helicopter       |X: : : : :  | : : : :  | : : : : :  | : : : :  | : : :  | :  |
|     |teams                      |X: : : : :  | : : : :  | : : : : :  | : : : :  | : : :  | :  |
---------------------------------------------------------------------------------------------
|Y(60)|Number of personnel        |X: : : : :  | : : : :  | : : : : :  | : : : :  | : : :  | :  |
|     |per MSS                    |X: : : : :  | : : : :  | : : : : :  | : : : :  | : : :  | :  |
---------------------------------------------------------------------------------------------
```

		X(1)					X(2)				X(3)					X(4)				X(5)			X(6)
																				X			
	Z(j)	1	3	4	8	D	3	4	8	D	2	5	6	7	D	3	4	8	D	4	8	D	D
Y(61)	Number in van team	X																					
Y(62)	Number of FDD personnel per CMF	X										X											
Y(63)	Number of FDD personnel per OB	X										X											
Y(64)	Number of FDD personnel per DAA	X										X											
Y(65)	Fraction of no-launch failures req. helicopter		X	X			X	X								X	X			X		X	
Y(66)	Number of persons at CAMMS need to know missile loc.					X																	
Y(67)	Shell-game cycle time (minutes)					X																	
Y(68)	Average pay for CMF personnel ($)											X											
Y(69)	Average pay for OB personnel ($)											X											
Y(70)	Average pay for DAA personnel ($)											X											

		X(1)					X(2)				X(3)					X(4)				X(5)			X(6)
																				X			
	Z(j)	1	3	4	8	D	3	4	8	D	2	5	6	7	D	3	4	8	D	4	8	D	D
Y(71)	Cost per STV ($)												X										
Y(72)	Cost per CMF ($)										X												
Y(73)	Cost per OB ($)										X												
Y(74)	Cost per DAA ($)										X												
Y(75)	Equipment cost per CMF ($)										X												
Y(76)	Equipment cost per OB ($)										X												
Y(77)	Equipment cost per DAA ($)										X												
Y(78)	Inventory cost per CMF ($)													X									
Y(79)	Inventory cost per OB ($)													X									
Y(80)	Inventory cost per DAA ($)													X									

		X(1)					X(2)				X(3)					X(4)				X(5)			X(6)
																				X			
	Z(j)	1	3	4	8	D	3	4	8	D	2	5	6	7	D	3	4	8	D	4	8	D	D
Y(81)	Number of cranes/cluster												X										X
													X										X
Y(82)	Number of crane teams											X											
												X											
Y(83)	Seven days crane reliability																						X
																							X
Y(84)	Minimum number of cranes needed per cluster																						X
																							X
Y(85)	Cost per crane ($)												X										
													X										
Y(86)	Number of helicopter teams											X											
												X											
Y(87)	Number of van teams											X											
												X											
Y(88)	Number of security teams for FDD	X										X											
		X										X											
Y(89)	Number in FDD security team	X																					
		X																					
Y(90)	Personnel cost/FDD security team											X											
												X											

		X(1)					X(2)				X(3)					X(4)				X(5)			X(6)
																				X			
	Z(j)	1	3	4	8	D	3	4	8	D	2	5	6	7	D	3	4	8	D	4	8	D	D
Y(91)	Personnel cost/crane team											X											
Y(92)	SAL verifications (at least once per year)			X				X									X		X	X		X	
Y(93)	Time spent at each PS for PLU (minute)			X				X									X		X	X			
Y(94)	Time to enter/exit site (minute)		X				X									X				X			

Appendix B - Computer Listing of Models

```
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION Y(6),Z(7),ALPHA(6),BIG(6),SMALL(6)
      DIMENSION X(33)
C
      ALPHA(1) = 2.31D-1
      ALPHA(2) = 2.19D-1
      ALPHA(3) = -1.29D-1
      ALPHA(4) = 1.81D-1
      ALPHA(5) = 1.66D-1
      ALPHA(6) = 1.4D-2
      BIG(1) = 3.2135580766270D2
      BIG(2) = 9.9574552506372D-1
      BIG(3) = 3.2613572445920D1
      BIG(4) = 8.3794271472430D-4
      BIG(5) = 9.3456144255530D-4
      BIG(6) = 9.9999999999950D-1
      SMALL(1) = 3.0442708478280D2
      SMALL(2) = 9.9566182135760D-1
      SMALL(3) = 1.5320157195250D1
      SMALL(4) = 8.1695634220310D-4
      SMALL(5) = 8.9576831675680D-4
      SMALL(6) = 9.9997700128790D-1
C
      DO 2 I = 1,33
      READ (1,1) X(I)
      WRITE (6,1) X(I)
    1 FORMAT (V)
    2 CONTINUE
C
   10 Z(1) = X(2)*X(7) + X(3)*X(8) + X(4)*6. + X(5)*X(9) +
     &        X(6)*2. + 20.*X(14) + X(10)*3. + X(11)*2.
     &        + 200.*5. + 200.*X(21) + X(1)*X(22) + X(20)*X(23)
     &        + X(33)*2.
      Z(2) = 200.*1.E6 + X(1)*5.E7 + X(20)*5.E7 + 200.*X(25)
     &         + X(1)*X(26) + X(20)*1.E8
      Z(3) = 0.0008/.1208 * (31.16+X(12)+1.16+
     &        1.) + .18/.1308*(30.+X(13)+1.)
      Z(4) = 7.000/1.232D3*(1.0D4+1.1D1*(7.0D3+3.0D0))) + 5.75003*
     &        3.0D-4/1.805D-1 + 1.000*(1.000/1.201 - 8.0D-4) + 1.4D5/
     &        3.26003 + 1.4D5*5D-2/8.863 + 1.6D2 + 3.001
      Z(5) = (1.33*(X(2)*X(17) + X(3)*X(18) + X(5)*X(15)
     &        + X(6)*4.E4 + 20.*X(16) + 2.6E6 +
     &        X(31)*6.E4 + 4.E4*X(32) + 200.*X(21)*2.E4 +
     &        X(1)*X(22)*2.E4 + X(20)*X(23)*2.5E4 + X(33)*
     &        4.E4 + 100.*6.E4)*10.)*6.7101
      Z(6) = X(10)*1.E6 + X(11)*2.E4 + 4.E7 + X(12)*2.E5
     &        + 200.*X(30)*5.E5
      Z(7) = 200.*X(27) + X(1)*X(28) + X(20)*X(29)
```

```
      TOTAL = 43200.0
      Y(1) = Z(1)/(X(2)*X(7)+X(4)*6.+1000.)
     & + TOTAL/(0.1808*(Z(3)+Z(4)))
      Y(2) = (TOTAL - .1808*(Z(4)+Z(3)))/TOTAL
      Y(3) =(Z(2)+Z(5)+Z(6)+Z(7))*(-1)
      Y(4) = .1808*(Z(4)-1.*(0.0004+0.0004-1./12.)*5760.
     &        -480.+1.465/3960.-180.+11.*(7000./1232.
     &        +8.)+Z(3))/172368.
      Y(5) = 200.*(0.0032*1.465/2200. + (Y(4)*11.97/
     &        (3.*(X(10)+X(11)+200.+X(19)))) + .1808*(44.*7000./
     &        1232.+4.*1.64/1232.))/(43200.*(X(10)+
     &        X(11)+200.+X(19)))
      SUM = 0.0
      NTIMES = IFIX(X(30) - 2.) + 1
      DO 30 I = 1,NTIMES
      II = I-1
      SUM = SUM + IFACT(IFIX(X(30)))/(IFACT(IFIX(2.+II))*
     &      IFACT(IFIX(X(30)-2.-II))) * 0.999**(2+II)
     &      * (1.-0.999)**(IFIX(X(30)-2-II))
   30 CONTINUE
      Y(6) = SUM
C
      DO 35 K =1,6
      Y(K) = (Y(K) - SMALL(K))/(BIG(K) - SMALL(K))
   35 CONTINUE
      VAL = 0.0
      DO 40 J = 1,6
      VAL = VAL + ALPHA(J)*Y(J)
   40 CONTINUE
      WRITE (5,50) VAL
   50 FORMAT (//,'CRITERION FUNCTION VALUE = ',D20.13)
      STOP
      END
C
      FUNCTION IFACT(III)
      IF (III .LT. 0) GO TO 20
      IF (III .EQ. 0) GO TO 40
      IFACT = 1
      DO 10 J = 1,III
      IFACT = IFACT*J
   10 CONTINUE
      RETURN
   20 WRITE (6,30)
   30 FORMAT (//,1X,'Factorial on a negative number is not allowed.',//
      RETURN
   40 IFACT = 1
      RETURN
      END
```

APPENDIX C

C-I. Introduction

The development of the MX maintenance simulation system has changed direction in the past year. The previous model required that the clusters and maintenance facilities have their location coordinates specified as model input and this required a rather large amount of input data. At the current state of MX development this amount of detail and precision did not prove necessary, and made model testing clumsy when only basic concepts of MX maintenance were involved. Further, the model was designed around a vertical launch concept, and some features of the model had application with that type of launch mode only, thus requiring correction.

A more generalized approach was necessary, one that would allow a model to be quickly configured and evaluated. Since the MX system design is continuously changing and evolving, the maintenance simulation system should be able to easily and quickly model and test proposed changes and effects on maintenance. It was felt that a special purpose modelling language would fill a need in the MX program, and this language has been developed and named SIMMX (Simulation of Maintenance on MX). The objectives of the language were as follows:

1. It would be easy to learn for those engaged in the MX missile program. The vocabulary, abbreviations, and conventions of MX should be usable.
2. The language should be capable of implementation on

a wide variety of computer systems. Since the computer system that the Air Force would like to use for SIMMX is not now predictable, the simulation should be usable on any medium to large scale computer system. The language should also be usable in either a batch or a time sharing environment.

3. Models written in SIMMX should have their logic and structure apparent to other MX personnel who examine it.

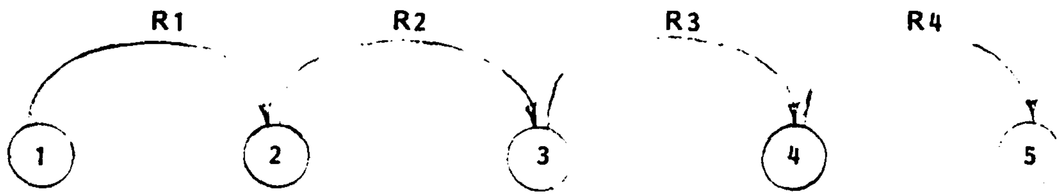
4. Models written in the language should be easily modifield, and the results of the modification quickly determined.

C-II. Using SIMMX

The modeler who wishes to use SIMMX, first describes the maintenance strategy in a network form. A network allows a visual representation of the procedure priorities of the maintenance tasks. The information represented in the network is then described in the SIMMX language, and entered into the computer. The computer then simulates the activity and presents the results of the simulation.

In order to demonstrate the SIMMX language, a theoretical maintenance plan will be described and its simulation executed. Figures C-1, C-2, C-3, and C-4 show the maintenance strategy that will be modeled in network form. Each figure gives the strategy for

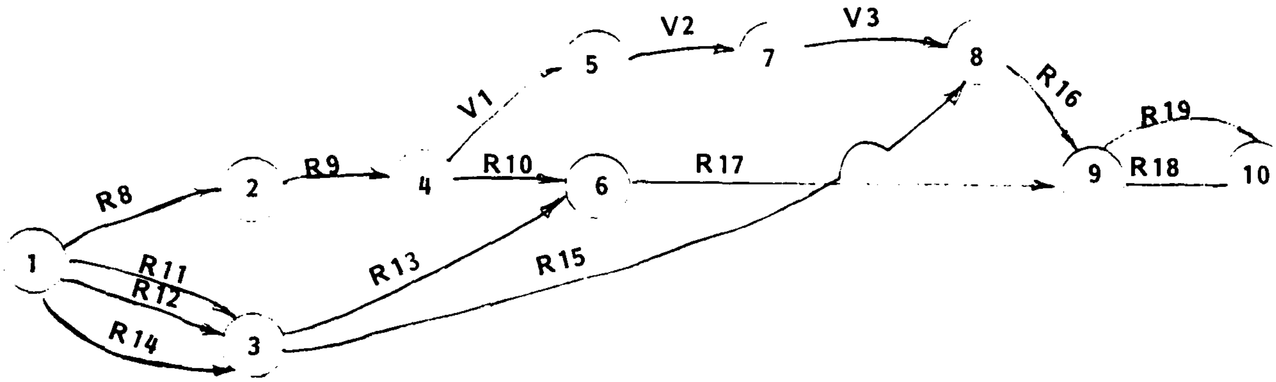
RESIDENT OPERATIONAL SUPPORT EQUIPMENT REPAIR (ROSE)



R1	NOR:	5, .1	CRWA	Briefing
R2	NOR:	1, .2	CRWA, VANA	Travel
R3	NOR:	5.25, .6	CRWA, VANA	Repair
R4	NOR:	1.25, .3	CRWA, VANA	Return & Debrief

Figure C-1: ROSE Maintenance Network

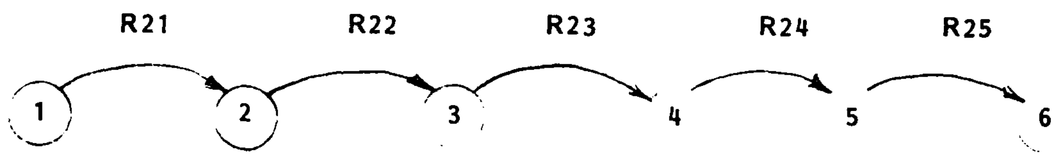
BOOSTER CANISTER SYSTEM REPAIR (B/C)



R8	NOR: .5, .1	MSS	MSS Dispatched
R9	NOR: 10, 2	MSS	Shell Game Pick up
R10	NOR: 3, .08	MSS	Return to CMF
R11	NOR: 48, 6	CRWB	Barrier Removed
R12	NOR: 6, 1	STV	STV (EMP) to Barrier
R13	NOR: 5, .1	STV	STV (EMP) to CMF
R14	NOR: 6, 1	STV	New B/C to Barrier
R15	NOR: 3,.08	STV	New B/C to
R16	NOR: 10, 2	MSS, STV	Shell game
R17	NOR: 6, 1	STV	Def.B/C to DAA
R18	NOR: 48, 6	CRWB	Barrier replaced
R19	NOR: 6, 1	STV	STV (EMP) to CMF
V1	NOR: 10, 2	CRN	Remove lids
V2	NOR: 24, 0	Team	Verification
V3	NOR: 10, 2	CRN	Replace lids

Figure C-2: B/C Maintenance Network

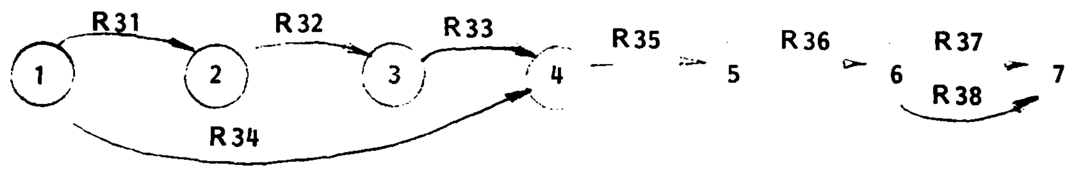
Mobil OSE and MGCS Repair (MGCS)



R21	NOR: 5, .1	MSS	MSS Dispatched
R22	NOR: 10, 1.5	MSS	Shell Game P. U.
R23	NOR: 3, .08	MSS	Return to CMF
R24	NOR: 6, 9	CRWA	Repair at CMF
R25	NOR: 10, 1.5	MSS	Shell Game Reinstalled

Figure C-3: MGCS Maintenance Network

Reentry System (RS)



R31	NOR: .5, .1	MSS	MSS Dispatched
R32	NOR: 10 , 1.5	MSS	Shell Game P.U.
R33	NOR: 3, .08	MSS	Return to CMF
R34	NOR: 1, .2	VANA	Travel to CMF
R35	NOR: 5, 1.2	VANA, MSS	Repair/Replace
R36	NOR: 5, .09	CRWA	Functional Checking
R37	NOR: 10, 1.5	MSS	Shell Game Installed
R38	NOR: 1, .5	VANA	Return

Figure C-4: RS Maintenance Network

each failure type that can occur in the model. For example, Figure C-1 shows the tasks involved when there is a Resident Operational Support Equipment failure (ROSE). There are five tasks involved: R1, R2, R3, R4, and R5. Each task is represented by an arrow on the network, and each task must be originated and terminated by a numbered node. The network shows that each of the tasks must be performed in sequence, and none can start before its predecessor is completed. The table below the network gives the time of each task, and the maintenance entities required for each one. The table indicates that the time for task R1 is normally distributed with a mean of 0.5 hrs. and a standard deviation of 0.1 hrs. The maintenance entity required is CRWA (Crew A). The names assigned to the tasks and entities are arbitrary and left to the choice of the modeler. The last column of the table gives a brief description of the task. Rask R1 is a crew briefing before they begin the repair tasks. The times for the tasks can be constants, or random values from specified probability distributions.

The networks can be quite simple, as in the ROSE failure, or much more complex, as with a Booster Canister System Failure, Figure C-2. One can see in a B/C failure that four tasks, R8, R11, R12, and R14, can begin simultaneously as soon as a B/C failure occurs. The networks provide a simple, graphical representation of a maintenance plan. The preparation of the networks appears to give insight to MX maintenance problems that would not have been available otherwise. Each time networks, of this type, are presented to groups of MX planners, discussions and questions are generated that provide valuable

information. The capability of simulating the networks, using SIMMX makes them even more valuable.

Figure C-5 shows the complete SIMMX program that will simulate the maintenance plan described in the networks. It should be emphasized that any sub-set of the maintenance plan can be simulated separately. For example, if a modeler was investigating just the ROSE maintenance tasks, a SIMMX program could be prepared containing only those elements, and a simulation of that portion of the plan could be executed. All of the statements in Figure C-5 are free form, and there are not rules for the columns in which statements must start. The indentations and spacing in Figure C-5 are for program readability and are not required for execution. There are presently seven sections in a SIMMX program. Each section must be started on a new line, and each section must be terminated with a semi-colon. The seven sections are named SITE, MISSILE, EQUIPMENTS, TASKS, FAILURES, NETWORKS and SIMULATE. Comments may be placed anywhere in a SIMMX program and start with a dollar sign. Each section will now be discussed in detail.

SITES

In this section the modeler specifies how many launch sites are to be included in each cluster. In the example program, Figure C-5, this is set at 23. In the present version of SIMMX, only a single cluster may be simulated.

```
SITES=23;
MISSILE=1;
 EQUIPMENTS=CRWA(0,8,8.00),VANA(0,8,8.00),MSS(0,8,8.00),CRWB(0,7,9.0)
           ,STV(0,8,8.00),CRN(0,10,8.00),TEAM(1,10,7.00) ;
 TASKS= R1,N(.5,.1),CRWA(1) : $ BRIEFING
        R2,N(1.,.2),CRWA(1),VANA(1) : $ TRAVEL
        R3,*,N(5.25,.6),CRWA(1),VANA(1) : $ REPAIR
        R4,N(1.25,.3),CRWA(1),VANA(1) : $ RETURN AND DEBRIEF
        R8,N(.5,.1),MSS(1) :  $ MSS DISPATCHED
        R9,N(10.,1.5),MSS(1): $ SHELL GAME TO PICK UP
       R10,N(3.,.08),MSS(1) : $ RETURN TO CMF
       R11,N(48.,6.),CRWB(1): $ BARRIER REMOVED
       R12,N(6.,1.),STV(1) :  $ STV(EMP) TO BARRIER
       R13,N(.5,.1),STV(1) :  $ STV(EMP) TO CMF
       R14,N(6.,1.),STV(1) :  $ NEW B/C TO BARRIER
       R15,N(3.,.08),STV(1) : $ NEW B/C TO SITES
        R16,*,N(10.,1.5),MSS(1),STV(1) : $SHELL GAME INSTALLED
       R17,N(6.,1.),STV(1) :  $ DEF B/C TO DAA
       R18,N(48.,6.),CRWB(1): $ BARRIER REBUILT
       R19,N(6.,1.),STV(1) :  $ STV(EMP) TO CMF
        V1,N(10.,1.5),CRN(1): $ REMOVE LIDS
        V2,N(24.,.05),TEAM(1):$ VERIFICATION
        V3,N(10.,1.5),CRN(1) : $ REPLACE LIDS
        R21,N(.5,.1),MSS(1) : $ MSS DISPATCHED
        R22,N(10.,1.5),MSS(1) : $ MSS SHELL GAME P.U.
        R23,N(3.,0.08),MSS(1) : $ MSS RETURN TO CMF
        R24,*,N(6.,0.9),CRWA(1) : $ REPAIR AT CMF
        R25,N(10.,1.5),MSS(1) : $ SHELL GAME INSTALLED
        R31,N(.5,.1),MSS(1) : $ MSS DISPATCHED
        R32,N(10.,1.5),MSS(1) : $ SHELL GAME P.U.
        R33,N(3.0,0.08),MSS(1) : $ RETURN TO CMF
        R34,N(5.,1.0),VANA(1) : $ TRAVEL TO CMF
        R35,*,N(5.,1.2),VANA(1),MSS(1) : $ REPAIR/REPLACE
        R36,N(5.,.09),CRWA(1) : $ FUNCTIONAL CHECKING
        R37,N(10.,1.5),MSS(1) : $ SHELL GAME INSTALLED
        R38,N(1.3,.04),VANA(1) : $ RETURN
 FAILURES=ROSE,SITE,300,LAUNCHABLE :
           B/C,MISSILE,600,UNLAUNCHABLE :
         MGCS,MISSILE,250,UNLAUNCHABLE :
         R-S,MISSILE,380,UNLAUNCHABLE ;
 NETWORKS=ROSE,(1-2,R1),(2-3,R2),(3-4,R3),(4-5,R4) :
           B/C,(1-2,R8),(2-4,R9),(4-6,R10),(1-3,R11),(1-3,R12) ,
               (3-6,R13),(1-3,R14),(3-8,R15),(8-9,R16),(6-9,R17),
               (9-10,R18),(9-10,R19),(4-5,V1),(5-7,V2),(7-8,V3) :
         MGCS,(1-2,R21),(2-3,R22),(3-4,R23),(4-5,R24),(5-6,R25) :
         R-S,(1-2,R31),(2-3,R32),(3-4,R33),(1-4,R34),(4-5,R35),
              (5-6,R36),(6-7,R37),(6-7,R38) ;
 SIMULATE=1200.0,24.0 ;
```

Figure C-5: SIMMX Program

MISSILES

The number of missiles per cluster is set in this command. In the example, one missile per cluster is specified.

EQUIPMENTS

Information on the repair facilities is given in this section. It shows each of the entities that are required for the repair tasks, how many of them are to be available, and when they are to be available. In the sample program, Figure C-5, in the EQUIPMENT section a segment of the section shows:

CRWA (U, 8, 8.00)

This indicates there is a maintenance entity named CRWA that will be required on maintenance tasks during the simulation. The U specifies that the number of CRWA's will be unlimited. Thus no task will be delayed because of a lack of CRWA. The segment "8, 8.00" indicates that CRWA s will only be available for eight hours each 24 hour period, and the start time for their availability will be 0800 hours. Thus, CRWA's will only be available from 0800 to 1600 hours each day. The other maintenance entities are described in a similar manner. The modeler may specify either a fixed number, or unlimited, for the number of each type of entity. For example, the entity TEAM has only one unit available. If at some point during the simulation TEAM is occupied on a task, and another task occurs that requires TEAM, the second task will be delayed until the first task is completed.

TASKS

The TASKS section of the program lists the information on each task that can take place during the simulation and each task that appears on a network will be shown in this section. The task code, the time required to complete the task, and the maintenance entity(s) required for the task are shown. It should be noted in the example that some of the tasks are marked with an asterisk. These tasks, when completed, cause the system that failed to be put back into the ready status. Task R3 is one of these types of tasks. Task R3 occurs in the ROSE network, Figure C-1, and it can be seen that this the actual repair task for that type of failure. The number of units of the maintenance entity required to complete each task is shown after the name of the entity. CRWA (1), means that one unit of CRWA is required for the task.

FAILURES

Information on each of the type of failures is included in this section. The name of the failure, the unit to which it applies, the time between the failures, and the status of the missile during the failure is shown. For example the statement:

ROSE, SITE, 300, LAUNCHABLE

indicates first that a ROSE failure is referenced. A ROSE failure can occur at each site in the model, and the average time between the failures is 300 hours and the system assumes a Poisson failure rate. The missile remains launchable when this type of failure occurs. Each of the failures that can occur during the simulation is shown in a similar manner.

NETWORKS

The structure of the network is described in this section of the SIMMX program. The name of the network is given, and then each task in the network is shown along with the task's beginning and ending node. A colon (:) designates the end of each network, and a semi-colon (;) terminates the entire section.

SIMULATE

The desired length of the simulation and the reporting interval is given in this section. For the example, the simulation is to last 1200 hours and the model is to report on the status of the system every 24.0 hours.

C-III. Model Output

The output from the example SIMMX program is shown in Figures C-6 through C-12. The output in Figures C-6 through C-9 are generated before the simulation begins, and document the parameters of the model. In Figure C-6 the amount of availability for most of the resources is set at 100,000 units. This results from the modeler specifying that there was to be unlimited amounts of these entities.

Output from the simulation phase begins in Figure 10. It shows the beginning and end of each activity that occurs during the simulation. In most cases this level of detail is not required, and later versions of SIMMX will provide the modeler an opportunity to select the level of out put. Any activity that is started, will stop when the availability period for its maintenance resource(s) is ended. The activity will resume the

```
************************************
*                                  *
*                                  *
*   SIMULATION OF THE MX MISSILE   *
*  VERIFIABLE HORIZONTAL SHELTERS  *
*                                  *
*                                  *
************************************

      MODEL IS SIMULATED FOR    1200.000 HOURS

            MODEL INFORMATIONS
            ===== ============

  NUMBER OF SITES PER CLUSTER    =  23
  NUMBER OF MISSILE PER CLUSTER  =   1
```

TYPE OF FAILURE	MEAN TIME BETWEEN FAILURE	SEVERITY OF FAILURE
ROSE	300.00	LAUNCHABLE
B/C	600.00	UNLAUNCHABLE
MGCS	250.00	UNLAUNCHABLE
R-S	380.00	UNLAUNCHABLE

RESOURCES INFORMATIONS

TYPE	CRWA	VANA	MSS	CRWB	STV	CRN	TEAM
AMOUNT OF AVAILABILITY	100000	100000	100000	100000	100000	100000	1
TOTAL TIME AVAILABLE/DAY	8.00	8.00	8.00	7.00	8.00	10.00	10.00
STARTING TIME	8.00	8.00	8.00	9.00	8.00	6.00	7.00

Figure C-6: SIMMX Output - Pre-Simulation Phase

NETWORK DESCRIPTIONS
======= ============

TYPE	:	ROSE
TIME BETWEEN FAILURES	:	300.00
PLACE OF FAILURE	:	SITE
SERVERITY OF FAILURE	:	LAUNCHABLE

START NODE	TASK NAME	TIME DURATION PARAMETERS DISTRIBUTION	MEAN	MIN/SD	MAX	TERMINATED NODE	EQUIPMENT TYPE	NO.
1	R1	NORMAL	.50	.10	0.00	2	CRWA	1
2	R2	NORMAL	1.00	.20	0.00	3	CRWA	1
							VANA	1
3	R3	NORMAL	5.25	.60	0.00	4	CRWA	1
							VANA	1
4	R4	NORMAL	1.25	.30	0.00	5	CRWA	1
							VANA	1
5	THIS IS ENDING NODE OF THE NETWORK							

Figure C-7: SIMMX Output - Pre-Simulation Phase

TYPE : B/C
TIME BETWEEN FAILURES : 600.00
PLACE OF FAILURE : MISSILE
SERVERITY OF FAILURE : UNLAUNCHABLE

START NODE	TASK NAME	TIME DURATION PARAMETERS DISTRIBUTION	MEAN	MIN/SD	MAX	TERMINATED NODE	EQUIPMENT TYPE	NO.
1	R8	NORMAL	.50	.10	0.00	2	MSS	1
1	R11	NORMAL	48.00	6.00	0.00	3	CPWR	1
1	R12	NORMAL	6.00	1.00	0.00	3	STV	1
1	R14	NORMAL	6.00	1.00	0.00	3	STV	1
2	R9	NORMAL	10.00	1.50	0.00	4	MSS	1
4	R10	NORMAL	3.00	.08	0.00	6	MSS	1
4	V1	NORMAL	10.00	1.50	0.00	5	CRN	1
6	R17	NORMAL	6.00	1.00	0.00	9	STV	1
3	R13	NORMAL	.50	.10	0.00	8	STV	1
3	R15	NORMAL	3.00	.08	0.00	8	STV	1
8	R16	NORMAL	10.00	1.50	0.00	9	MSS STV	1 1
9	R18	NORMAL	48.00	6.00	0.00	10	CRWB	1
9	R19	NORMAL	6.00	1.00	0.00	10	STV	1
10	THIS IS ENDING NODE OF THE NETWORK							
5	V2	NORMAL	24.00	.05	0.00	7	TEAM	1
7	V3	NORMAL	10.00	1.50	0.00	6	CRN	1

Figure C-8: SIMMX Output - Pre-Simulation Phase

TYPE : MGCS
TIME BETWEEN FAILURES : 250.00
PLACE OF FAILURE : MISSILE
SERVERITY OF FAILURE : UNLAUNCHABLE

START NODE	TASK NAME	TIME DURATION PARAMETERS DISTRIBUTION	MEAN	MIN/SD	MAX	TERMINATED NODE	EQUIPMENT TYPE	NO.
1	R21	NORMAL	.50	.10	0.00	2	MSS	1
2	R22	NORMAL	10.00	1.50	0.00	3	MSS	1
3	R23	NORMAL	3.00	.08	0.00	4	MSS	1
4	R24	NORMAL	6.00	.90	0.00	5	CRWA	1
5	R25	NORMAL	10.00	1.50	0.00	6	MSS	1
6	THIS IS ENDING NODE OF THE NETWORK							

TYPE : R-S
TIME BETWEEN FAILURES : 380.00
PLACE OF FAILURE : MISSILE
SERVERITY OF FAILURE : UNLAUNCHABLE

START NODE	TASK NAME	TIME DURATION PARAMETERS DISTRIBUTION	MEAN	MIN/SD	MAX	TERMINATED NODE	EQUIPMENT TYPE	NO.
1	R31	NORMAL	.50	.10	0.00	2	MSS	1
1	R34	NORMAL	5.00	1.00	0.00	4	VANA	1
2	R32	NORMAL	10.00	1.50	0.00	3	MSS	1
3	R33	NORMAL	3.00	.08	0.00	4	MSS	1
4	R35	NORMAL	5.00	1.20	0.00	5	VANA	1
							MSS	1
5	R36	NORMAL	5.00	.09	0.00	6	CRWA	1
6	R37	NORMAL	10.00	1.50	0.00	7	MSS	1
6	R38	NORMAL	1.30	.09	0.00	7	VANA	1
7	THIS IS ENDING NODE OF THE NETWORK							

Figure C-9: SIMMX Output - Simulation Phase

```
 SIMULATION STARTS AT CLOCK TIME = 0.00

TIME =      7.103       ROSE FAILS
TIME =      7.103 NODE   1 OF ROSE STARTS
                      TASK R1    DURATION =       .366
TIME =      8.000  EVENT CODE 21  -  TASK R1    STARTS
TIME =      8.366       TASK R1    DONE
TIME =      8.366 NODE   2 OF ROSE STARTS
                      TASK R2    DURATION =      1.116
TIME =      8.366  EVENT CODE 21  -  TASK R2    STARTS
TIME =      8.366  EVENT CODE 21  -  TASK R2    STARTS
TIME =      9.482       TASK R2    DONE
TIME =      9.482 NODE   3 OF ROSE STARTS
                      TASK R3    DURATION =      6.373
TIME =      9.482  EVENT CODE 21  -  TASK R3    STARTS
TIME =      9.482  EVENT CODE 21  -  TASK R3    STARTS
TIME =     15.855       TASK R3    DONE
TIME =     15.855 NODE   4 OF ROSE STARTS
                      TASK R4    DURATION =      1.414
TIME =     15.855  EVENT CODE 21  -  TASK R4    STARTS
TIME =     15.855  EVENT CODE 21  -  TASK R4    STARTS
TIME =     16.000  EVENT CODE 40  -  TASK R4    END-OF-DAY
TIME =     16.000  EVENT CODE 40  -  TASK R4    END-OF-DAY
TIME =     18.263       ROSE FAILS
TIME =     18.263 NODE   1 OF ROSE STARTS
                      TASK R1    DURATION =       .460

-----------------------------------------
          REPORT AT TIME =     24.000

      COMPONENT       STATUS
      ---------       ------
         ROSE          DOWN    LAUNCHABLE
         B/C           READY
         MGCS          READY
         R-S           READY

   MISSILE SYSTEM STATUS : LAUNCHABLE
-----------------------------------------
```

Figure C-10: SIMMX Output - Simulation Phase: t = 0 t = 24

```
TIME =     30.452      B/C  FAILS
TIME =     30.452 NODE  1 OF B/C  STARTS
                    TASK R8    DURATION =       .459
                    TASK R11   DURATION =     49.488
                    TASK R12   DURATION =      6.517
                    TASK R14   DURATION =      6.684
TIME =     32.000  EVENT CODE 21  -  TASK R4   STARTS
TIME =     32.000  EVENT CODE 21  -  TASK R4   STARTS
TIME =     32.000  EVENT CODE 21  -  TASK R1   STARTS
TIME =     32.000  EVENT CODE 21  -  TASK R8   STARTS
TIME =     32.000  EVENT CODE 21  -  TASK R12  STARTS
TIME =     32.000  EVENT CODE 21  -  TASK R14  STARTS
TIME =     32.459      TASK R8   DONE
TIME =     32.459 NODE  2 OF B/C  STARTS
                    TASK R9    DURATION =     11.812
TIME =     32.459  EVENT CODE 21  -  TASK R9   STARTS
TIME =     32.460      TASK R1   DONE
TIME =     32.460 NODE  2 OF ROSE STARTS
                    TASK R2    DURATION =      1.324
TIME =     32.460  EVENT CODE 21  -  TASK R2   STARTS
TIME =     32.460  EVENT CODE 21  -  TASK R2   STARTS
TIME =     33.000  EVENT CODE 21  -  TASK R11  STARTS
TIME =     33.123      TASK R4   DONE
TIME =     33.123      ROSE COMPLETED
TIME =     33.784      TASK R2   DONE
TIME =     33.784 NODE  3 OF ROSE STARTS
                    TASK R3    DURATION =      6.393
TIME =     33.784  EVENT CODE 21  -  TASK R3   STARTS
TIME =     33.784  EVENT CODE 21  -  TASK R3   STARTS
TIME =     38.517      TASK R12  DONE
TIME =     38.684      TASK R14  DONE
TIME =     40.000  EVENT CODE 40  -  TASK R9   END-OF-DAY
TIME =     40.000  EVENT CODE 40  -  TASK R11  END-OF-DAY
TIME =     40.000  EVENT CODE 40  -  TASK R3   END-OF-DAY

----------------------------------------
       REPORT AT TIME =     48.000

     COMPONENT       STATUS
     ---------       ------
       ROSE           DOWN   LAUNCHABLE
       B/C            DOWN   UNLAUNCHABLE
       MGCS           READY
       R-S            READY

   MISSILE SYSTEM STATUS : UNLAUNCHABLE
----------------------------------------
```

Figure C-11: SIMMX Output - Simulation Phase: t = 24 t = 48

```
--------------------------------------
        REPORT AT TIME =  1200.000

     COMPONENT        STATUS
     ---------        ------
        ROSE           READY
        B/C            DOWN    UNLAUNCHABLE
        MGCS           READY
        R-S            DOWN    UNLAUNCHABLE

   MISSILE SYSTEM STATUS : UNLAUNCHABLE
--------------------------------------



 E N D   O F   S I M U L A T I O N
 = = =   = =   = = = = = = = = = =



          SYSTEM SIMULATION SUMMARY
          ====== ========== =======

             FOR THE DURATION OF
               1200.00 HOURS


THE AVAILABILITY OF MISSILE AT CLUSTER IS =    .4341

PERCENTAGE OF RESOURCES UTILIZATIONS :        MAX. USED

                            CRWA =    .3053        3
                            VANA =    .3701        2
                            MSS  =    .2392        2
                            CRWB =    .6440        1
                            STV  =    .1081        2
                            CRN  =    .0961        1
                            TEAM =    .1327        1
```

Figure C-12: SIMMX Output - Simulation Phase: Summary Report

next day at the beginning of the availability period and continue until the required task duration time is reached Every 24.00 hours of simulated time a report is generated that shows the status of each component of the system. Figures C-10 and C-11 show the simulation output for the first 48 hours. Figure C-12 shows the summary report generated at the end of the simulation. For this maintenance strategy, and the given failure parameters, the missile was available 43.41% of the time. The availability of each of the maintenance entities is also shown, along with the maximum number of each of them required during the simulation. For example, there were three units of CRWA required during execution, and these three units were utilized 30.53% of the time.

C-IV. Discussion

The SIMMX language has evolved from earlier attempts by the University of Houston to develop a useful simulation system for MX maintenance problems. The system is now general enough so that any maintenance concept can be described and modeled in this language. The use of networks to describe maintenance strategies has proven to be very beneficial, and the networks provide a communication medium for MX planners so that a strategy under consideration can be visualized.

The interpreter for SIMMX has been entirely written in FORTRAN. Every effort has been made to use very standard FORTRAN, so that SIMMX may be implemented on a variety of computer systems. SIMMX is now running on CDC, IBM and Honeywell systems as of this date, and is relatively inexpensive to use.

This simulation is available in both a batch and interactive mode. The interactive version gives prompt messages to the user requesting required information. Additional effort needs to be done on the interactive version to make its use more convenient and responsive to modelers needs.

The present version of SIMMX allows simulation of a single cluster only. The simulation of multiple clusters in a single model is recommended. This would permit a modeler to examine the availability of an entire missile wing under the various maintenance strategies. While there would be some changes in the internal data structure of the present version to handle this capability, it does appear that it could be done without a large increase in computer time usage.

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